Would Martian Life Escape a Lab on Earth?

AIBO the Research Dog | Sarah Hrdy: Why Mothers Come First

Discover

VOL. 24, NO. 3

MARCH 2003

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Can the Brain Conquer Fear?

Neuroscientists explore ways to keep emotions from hijacking the mind

Primitive brain senses danger, stirs up fright, then anger
Modern, evolved brain battles with primitive brain for control

The evolved brain has little use for negative emotions that once increased our ancestors' chances of survival on the African savanna

[redacted]

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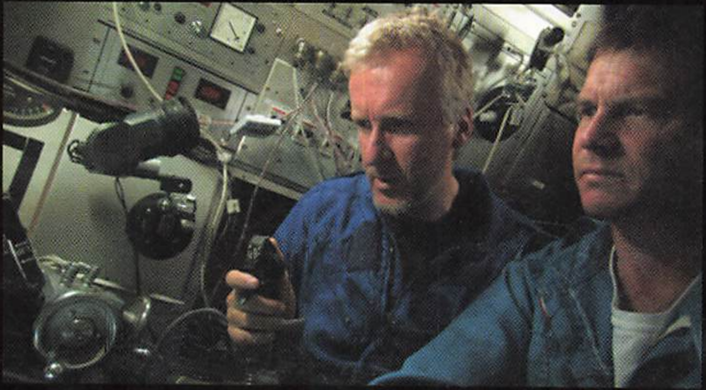

James Cameron (left), accompanied by actor Bill Paxton (right)

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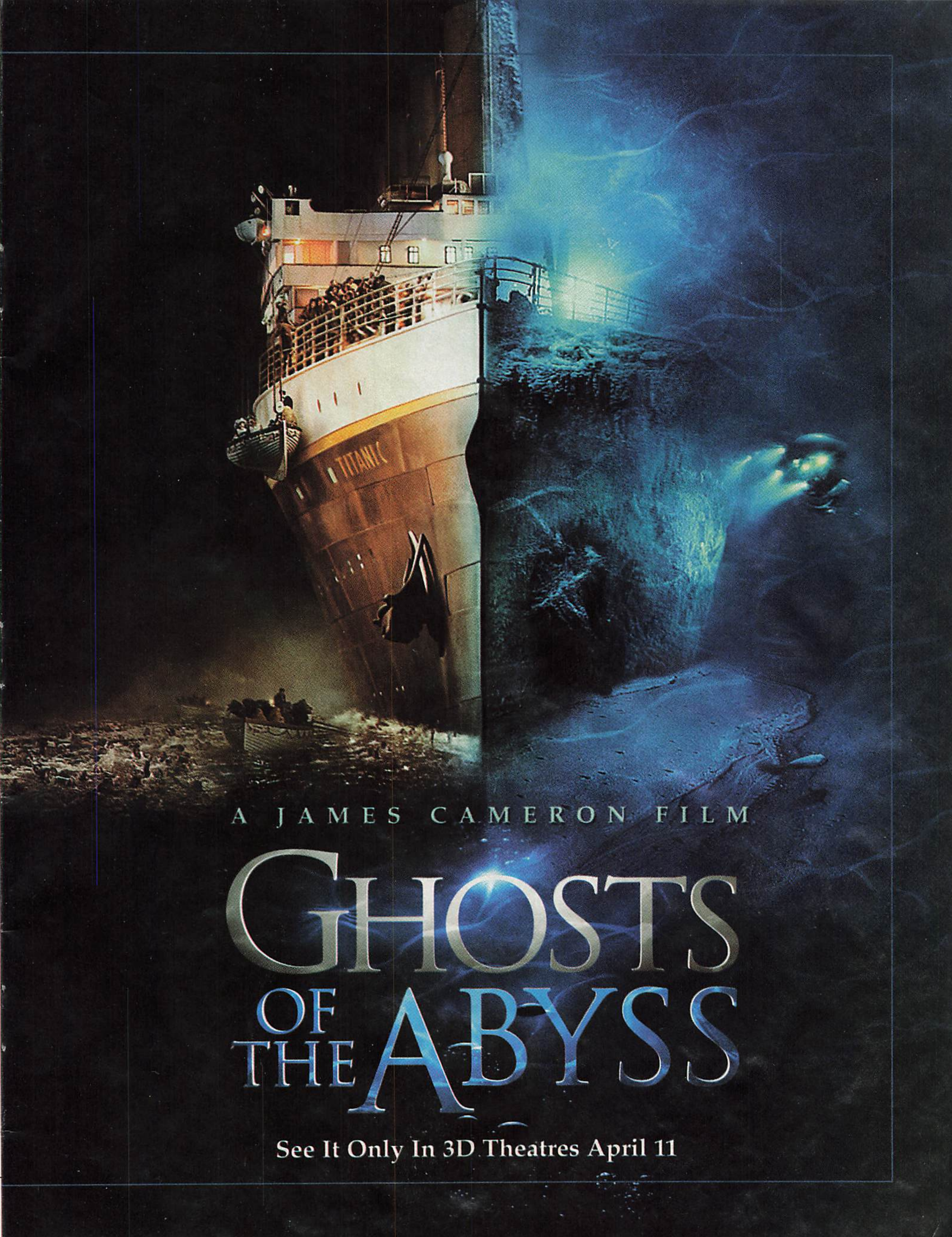
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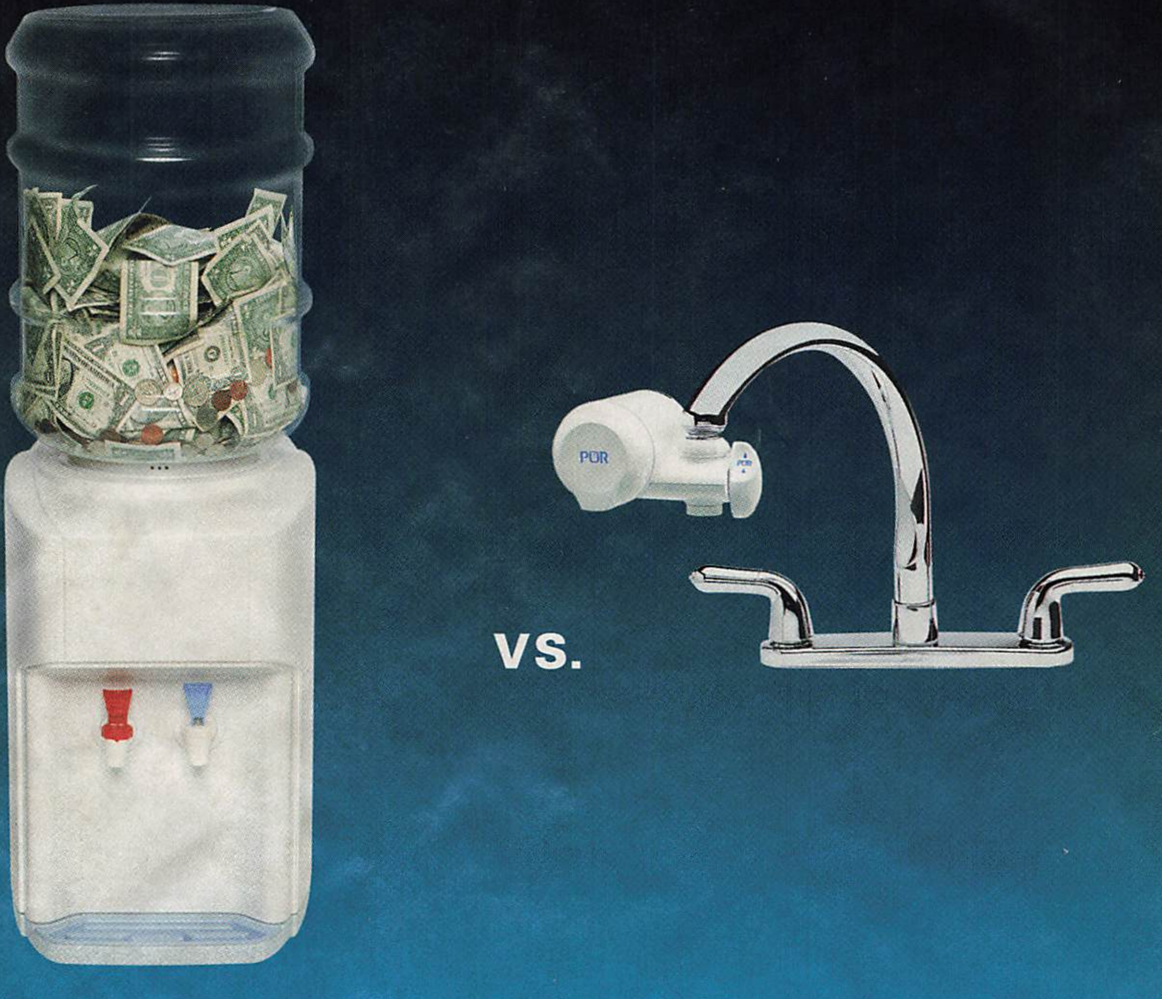

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RIGHT: HEPA AIR FILTERS AT THE SOUTHWEST FOUNDATION FOR BIOMEDICAL RESEARCH IN SAN ANTONIO HELP CORRAL SOME OF THE WORLD'S DEADLIEST MICROBES. STORY ON PAGE 60.
ON THE COVER: BY MAPPING THE PATHWAYS OF FEAR IN THE BRAIN, NEUROSCIENTISTS ARE UNCOVERING CLUES ABOUT HOW TO FREE THE CONSCIOUS MIND FROM ANCIENT FIGHT-OR-FLIGHT CONDITIONING. ILLUSTRATION BY DON FOLEY.

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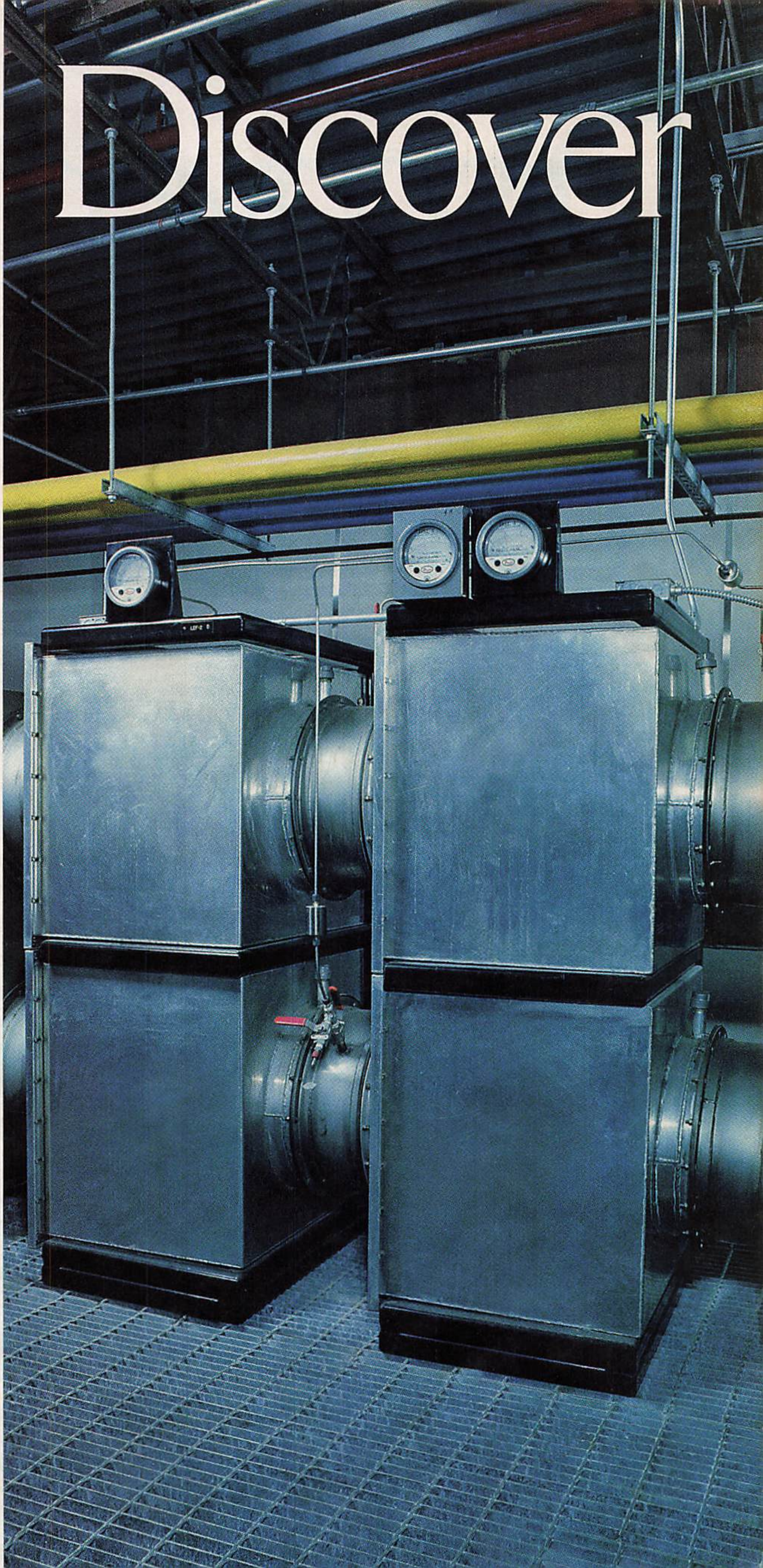
PHOTOGRAPH BY BRENT HUMPHREYS



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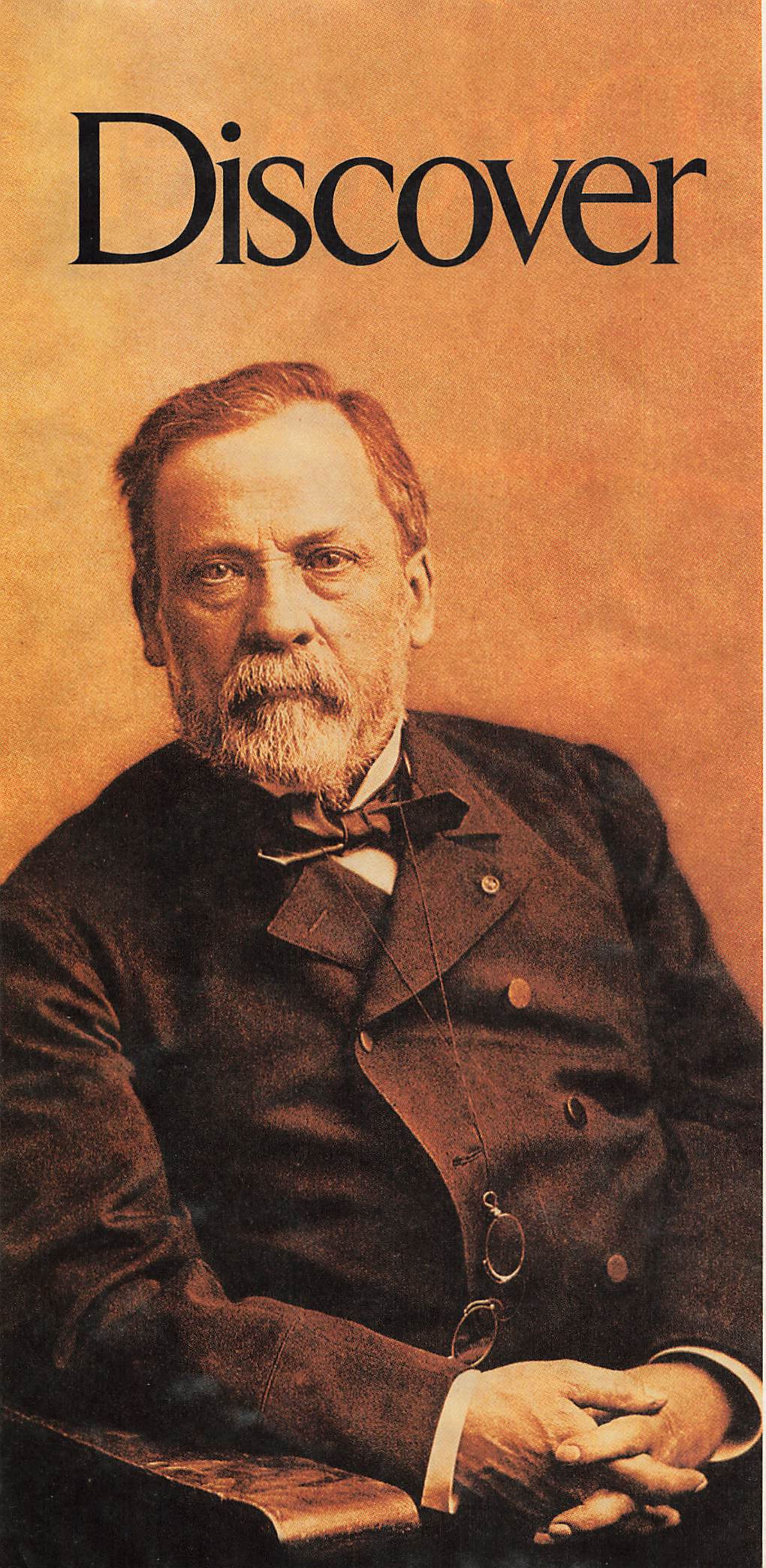

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LEFT: LOUIS PASTEUR, THE 19TH-CENTURY BIOLOGIST, CONDUCTED RESEARCH ON DISEASED SILKWORMS, SPOILED WINES, AND RUINED BEER. BUT HIS REAL TRIUMPHS WERE MEDICAL. SEE PAGE 22.

PHOTOGRAPH FROM ARCHIV/PHOTO RESEARCHERS.

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CLARINEX®
(desloratadine)
TABLETS

Brief Summary (For full Prescribing Information, see package insert.)

INDICATIONS AND USAGE: Allergic Rhinitis: CLARINEX Tablets 5 mg are indicated for the relief of the nasal and non-nasal symptoms of allergic rhinitis (seasonal and perennial) in patients 12 years of age and older.

Chronic Idiopathic Urticaria: CLARINEX Tablets are indicated for the symptomatic relief of pruritus, reduction in the number of hives, and size of hives, in patients with chronic idiopathic urticaria 12 years of age and older.

CONTRAINDICATIONS: CLARINEX Tablets 5 mg are contraindicated in patients who are hypersensitive to this medication or to any of its ingredients, or to loratadine.

PRECAUTIONS: Carcinogenesis, Mutagenesis, Impairment of Fertility: The carcinogenic potential of desloratadine was assessed using loratadine studies. In an 18-month study in mice and a 2-year study in rats, loratadine was administered in the diet at doses up to 40 mg/kg/day in mice (estimated desloratadine and desloratadine metabolite exposures were approximately 3 times the AUC in humans at the recommended daily oral dose) and 25 mg/kg/day in rats (estimated desloratadine and desloratadine metabolite exposures were approximately 30 times the AUC in humans at the recommended daily oral dose). Male mice given 40 mg/kg/day loratadine had a significantly higher incidence of hepatocellular tumors (combined adenomas and carcinomas) than concurrent controls. In rats, a significantly higher incidence of hepatocellular tumors (combined adenomas and carcinomas) was observed in males given 10 mg/kg/day and in males and females given 25 mg/kg/day. The estimated desloratadine and desloratadine metabolite exposures of rats given 10 mg/kg of loratadine were approximately 7 times the AUC in humans at the recommended daily oral dose. The clinical significance of these findings during long-term use of desloratadine is not known.

In genotoxicity studies with desloratadine, there was no evidence of genotoxic potential in a reverse mutation assay (*Salmonella/E. coli* mammalian microsome bacterial mutagenicity assay) or in two assays for chromosomal aberrations (human peripheral blood lymphocyte clastogenicity assay and mouse bone marrow micronucleus assay).

There was no effect on female fertility in rats at desloratadine doses up to 24 mg/kg/day (estimated desloratadine and desloratadine metabolite exposures were approximately 130 times the AUC in humans at the recommended daily oral dose). A male specific decrease in fertility, demonstrated by reduced female conception rates, decreased sperm numbers and motility, and histopathologic testicular changes, occurred at an oral desloratadine dose of 12 mg/kg in rats (estimated desloratadine exposures were approximately 45 times the AUC in humans at the recommended daily oral dose). Desloratadine had no effect on fertility in rats at an oral dose of 3 mg/kg/day (estimated desloratadine and desloratadine metabolite exposures were approximately 8 times the AUC in humans at the recommended daily oral dose).

Pregnancy Category C: Desloratadine was not teratogenic in rats at doses up to 48 mg/kg/day (estimated desloratadine and desloratadine metabolite exposures were approximately 210 times the AUC in humans at the recommended daily oral dose) or in rabbits at doses up to 60 mg/kg/day (estimated desloratadine exposures were approximately 230 times the AUC in humans at the recommended daily oral dose). In a separate study, an increase in preimplantation loss and a decreased number of implantations and fetuses were noted in female rats at 24 mg/kg (estimated desloratadine and desloratadine metabolite exposures were approximately 120 times the AUC in humans at the recommended daily oral dose). Reduced body weight and slow righting reflex were reported in pups at doses of 9 mg/kg/day or greater (estimated desloratadine and desloratadine metabolite exposures were approximately 50 times or greater than the AUC in humans at the recommended daily oral dose). Desloratadine had no effect on pup development at an oral dose of 3 mg/kg/day (estimated desloratadine and desloratadine metabolite exposures were approximately 7 times the AUC in humans at the recommended daily oral dose). There are, however, no adequate and well-controlled studies in pregnant women. Because animal reproduction studies are not always predictive of human response, desloratadine should be used during pregnancy only if clearly needed.

Nursing Mothers: Desloratadine passes into breast milk, therefore a decision should be made whether to discontinue nursing or to discontinue desloratadine, taking into account the importance of the drug to the mother.

Pediatric Use: The safety and effectiveness of CLARINEX Tablets in pediatric patients under 12 years of age have not been established.

Geriatric Use: Clinical studies of desloratadine did not include sufficient numbers of subjects aged 65 and over to determine whether they respond differently from younger subjects. Other reported clinical experience has not identified differences between the elderly and younger patients. In general, dose selection for an elderly patient should be cautious, reflecting the greater frequency of decreased hepatic, renal, or cardiac function, and of concomitant disease or other drug therapy. (see **CLINICAL PHARMACOLOGY – Special Populations**).

Information for Patients: Patients should be instructed to use CLARINEX Tablets as directed. As there are no food effects on bioavailability, patients can be instructed that CLARINEX Tablets may be taken without regard to meals. Patients should be advised not to increase the dose or dosing frequency as studies have not demonstrated increased effectiveness at higher doses and somnolence may occur.

ADVERSE REACTIONS: Allergic Rhinitis: In multiple-dose placebo-controlled trials, 2,834 patients received CLARINEX Tablets at doses of 2.5 mg to 20 mg daily, of whom 1,655 patients received the recommended daily dose of 5 mg. In patients receiving 5 mg daily, the rate of adverse events was similar between CLARINEX and placebo-treated patients. The percent of patients who withdrew prematurely due to adverse events was 2.4% in the CLARINEX group and 2.6% in the placebo group. There were no serious adverse events in these trials in patients receiving desloratadine. All adverse events that were reported by greater than or equal to 2% of patients who received the recommended daily dose of CLARINEX Tablets (5.0 mg once-daily), and that were more common with CLARINEX Tablet than placebo, are listed in Table 5.

Table 5

Incidence of Adverse Events Reported by ≥ 2% of Allergic Rhinitis Patients in Placebo-Controlled, Multiple-Dose Clinical Trials

Adverse Experience	CLARINEX Tablets 5 mg (n=1,655)	Placebo (n=1,652)
Pharyngitis	4.1%	2.0%
Dry Mouth	3.0%	1.9%
Myalgia	2.1%	1.8%
Fatigue	2.1%	1.2%
Somnolence	2.1%	1.8%
Dysmenorrhea	2.1%	1.6%

The frequency and magnitude of laboratory and electrocardiographic abnormalities were similar in CLARINEX and placebo-treated patients.

There were no differences in adverse events for subgroups of patients as defined by gender, age, or race.

Chronic Idiopathic Urticaria: In multiple-dose, placebo-controlled trials of chronic idiopathic urticaria, 211 patients received CLARINEX Tablets and 205 received placebo. Adverse events that were reported by greater than or equal to 2% of patients who received CLARINEX Tablets and that were more common with CLARINEX than placebo were (rates for CLARINEX and placebo, respectively): headache (14%, 13%), nausea (5%, 2%), fatigue (5%, 1%), dizziness (4%, 3%), pharyngitis (3%, 2%), dyspepsia (3%, 1%), and myalgia (3%, 1%).

The following spontaneous adverse events have been reported during the marketing of desloratadine: tachycardia, and rarely hypersensitivity reactions (such as rash, pruritus, urticaria, edema, dyspnea, and anaphylaxis), and elevated liver enzymes including bilirubin.

DRUG ABUSE AND DEPENDENCE: There is no information to indicate that abuse or dependency occurs with CLARINEX Tablets.

OVERDOSAGE: Information regarding acute overdosage is limited to experience from clinical trials conducted during the development of the CLARINEX product. In a dose ranging trial, at doses of 10 mg and 20 mg/day somnolence was reported.

Single daily doses of 45 mg were given to normal male and female volunteers for 10 days. All ECGs obtained in this study were manually read in a blinded fashion by a cardiologist. In CLARINEX-treated subjects, there was an increase in mean heart rate of 9.2 bpm relative to placebo. The QT interval was corrected for heart rate (QT_c) by both the Bazett and Fridericia methods. Using the QT_c (Bazett) there was a mean increase of 8.1 msec in CLARINEX-treated subjects relative to placebo. Using QT_c (Fridericia) there was a mean increase of 0.4 msec in CLARINEX-treated subjects relative to placebo. No clinically relevant adverse events were reported.

In the event of overdose, consider standard measures to remove any unabsorbed drug. Symptomatic and supportive treatment is recommended. Desloratadine and 3-hydroxydesloratadine are not eliminated by hemodialysis.

Lethality occurred in rats at oral doses of 250 mg/kg or greater (estimated desloratadine and desloratadine metabolite exposures were approximately 120 times the AUC in humans at the recommended daily oral dose). The oral median lethal dose in mice was 353 mg/kg (estimated desloratadine exposures were approximately 290 times the human daily oral dose on a mg/m^2 basis). No deaths occurred at oral doses up to 250 mg/kg in monkeys (estimated desloratadine exposures were approximately 810 times the human daily oral dose on a mg/m^2 basis).

Schering Corporation
Kenilworth, NJ 07033 USA

2/02 **23882116T-JBS**

U.S. Patent Nos. 4,659,716; 4,863,931; 4,804,666; 5,595,997; and 6,100,274.

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contributors

CLAUDIA GLENN DOWLING, a former senior staff writer for *Life*, is a fellow of the Explorer's Club who once climbed to advanced base camp on Mount Everest to record the behavior of ex-commandos intent on paragliding from the summit. In reporting her story on Sarah Blaffer Hrdy (page 40), Dowling was struck by the similarities between her role as a journalist and the role of her subject: "I observed this anthropologist in her natural habitat just as she once observed langur monkeys in their natural habitat."

BRENT HUMPHREYS, who specializes in travel and technology photography, was surprised when he arrived at a biosafety lab in Texas (page 60) on assignment for *Discover*. The contrast between life inside the lab and outside the lab was stark. "We were having barbecue in the break room, talking snowboarding," Humphreys says. "Thirty minutes later they were suited up for the ultimate biological defense." His photos have appeared in *MIT Technology Review, Newsweek, Fast Company, GQ,* and *Smart Business.*

CHRISTINE KENNEALLY, who holds a Ph.D. in psycholinguistics from Cambridge University, is a freelance writer whose articles on cognition, psychology, and language have appeared in *The New York Times, Slate,* and *Salon.* At a conference on language evolution, where she was doing research for her forthcoming book, *From Screech to Sonnet: The Origin and Evolution of Language,* Kenneally heard about Sony's robotic dog, called AIBO (page 46). "No human would mistake this metal thing for a dog, but in its mannerisms, AIBO is really doggy," she says. "It is absolutely seductive."

GEOF KERN, winner of the International Center of Photography's Infinity Award in applied photography and the Alfred Eisenstaedt Award for magazine photography, is often compared to René Magritte and Man Ray. In this issue Kern brings his typically surrealistic touch to an article on the runaway deer population in the United States (page 66). His work has also appeared in *The New York Times Magazine, Esquire, Elle, Life, Metropolis, American Photography, Entertainment Weekly,* and *The New Yorker.*

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letters

SEND IN THE CLONES

Jeff Wheelwright, our ostensible guide to the new world of human cloning ["Being Brave for This New World," Year in Science, January], minimizes the ethical and moral considerations that human cloning raises. The values Wheelwright champions—"economic and medical demands"—are chilling, suggesting that the worth of human cloning will lie in the commodification of life fostered by commerce and the laboratory. And biotech's role as the primary engine of development is hardly encouraging. Human cloning will become a reality because we just can't seem to help ourselves. And I submit that it is precisely that lack of self-restraint that makes us such risky tinkerers with life. Rather than "yield to the human clones" when ambiguities and disagreements face us, as Wheelwright advises, let us summon all the humility and caution within us, remembering that the very deepest value of life is intrinsic. We simply aren't the gods we too often take ourselves to be.

DAVID SEPPA
Portland, Oregon

CONCEALED CAUSE

Regarding "Headaches to Worry About" [Vital Signs, January]: Paul Austin made a brilliant diagnosis in this case [pseudotumor cerebri] and is to be commended. One thing strikes me as worthy of further inquiry: He describes Crystal as "a 22-year-old wearing heavy makeup." Was she wearing the heavy makeup because she had severe acne? If so, was she taking Accutane, prescribed either by her family physician or her dermatologist? One of the many side effects of Accutane is pseudotumor cerebri.

IAN D. MURPHY, M.D.
Toledo, Ohio

COLLISION COURSE

Karen Wright's article "Winging It" [Works in Progress, December] brought to my mind the possibility of an interesting correlation between the number of bird deaths caused by wireless-communication towers and the hypothesis that migratory birds rely on geomagnetic cues to assist in navigation. The U.S. Fish and Wildlife Service estimates that at least 5 million birds and as many as 50 million birds are killed annually in collisions with communications towers in the United States. I believe that further investigation should be devoted to the relationship between migratory-bird deaths and the wireless-communication tower signals interfering with a bird's ability to detect the magnetic field. Much research has been devoted to the potential impact that tower lighting has on orientation and navigation but not enough on the effects of the signal itself.

KEN BORN
Environmental Resource Policy Department
Monterey, California

SPEECH! SPEECH!

In "The Art of, um, Speaking Clearly" [R&D, November], it seems to me that psychologists Herbert Clark and Jean Fox Tree are approaching the art of speaking from two different directions. They posit that conversation sprinkled with *ums* and *uhs*, as a speaker searches for a thought or a word, adds sparkle to the dialogue. The article concludes with: "But woe betide the politician who allows such terms to intrude. 'When I say *uh* and *um* in conversation, I'm saying "I'm not ready to go on." If you're a public speaker, you don't want to be telling your audience that,' Clark says. A case in point: Not a single *uh* or *um* appears in the recorded inaugural speeches of American presidents between 1940 and 1996." There wouldn't be, or shouldn't be, any *ums* or *uhs* in a presidential inaugural or any public speaker's speech for two reasons: First, presidential inaugurals and most, if not all, political speeches are scripted; and second, experienced public speakers prepare to deliver their speech or their pitch, whereas conversation is entirely spontaneous. I believe we're talking, um, apples and oranges here.

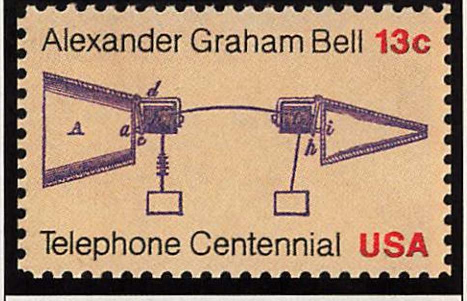
BILL SCHMEER
Thomasville, Pennsylvania

A NEW WRINKLE

In his response to a reader's question in Ask the Wizard [R&D, October], Richard Sontheimer of the University of Iowa College of Medicine incorrectly attributed wrinkling of the skin on the fingers after bathing to an accumulation of water in the stratum corneum of the skin. This process does occur, but it is not responsible for the wrinkles we associate with swimming or leisurely bathing. Wrinkling of the fingers is controlled by the autonomic nervous system via the sympathetic pathways in the sensory nerves. In 1973, O'Riain documented that a laceration of the digital nerves to the fingers will prevent wrinkles from forming on the fingers after any period of immersion. This fact is the basis of a common hand-surgery test (the wrinkle test) to determine nerve integrity in patients who are too young or are otherwise unable to report sensibility in the fingertips. Also, patients with leprosy, severe diabetes, or other severe peripheral nerve disorders are unable to form wrinkles in their fingers. Presumably the sympathetic reflex pathways act to cause contraction of the small muscle fibers that are attached to the deep skin layer and act to pull the fingertip skin into noticeable folds.

GREGORY BORAH, M.D.
Chief of Plastic Hand Surgery
Robert Wood Johnson Medical School
New Brunswick, New Jersey

Issued in March 1976.



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Richard Sontheimer responds: *Many dermatologists attribute water-related wrinkling of the skin on the fingers primarily to excessive hydration of the stratum corneum. Although the magnitude of this effect is not well documented, the role of the nervous system is even more ambiguous. There are published data supporting the idea that sympathetic nerve response can cause some such wrinkling, but this effect appears to be just one of several contributing factors. Some researchers have pointed out that children with cystic fibrosis—who have aberrations in the function of their autonomic nervous system—experience* premature *wrinkling after water immersion, not the delayed wrinkling one might expect. And while researchers have observed decreased water-related skin wrinkling in patients with diabetes, this phenomenon appears to be independent of the state of the patient's autonomic nervous system. It may be related to the well-recognized changes in thickness and rigidity of the skin of diabetics.*

HELP FROM DISCOVER

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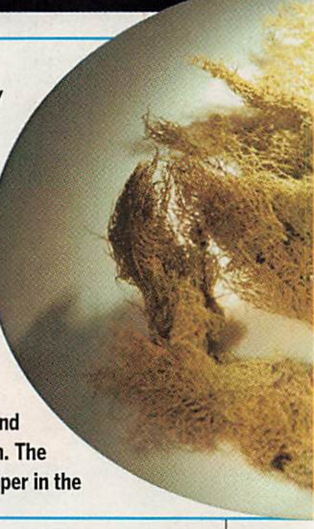
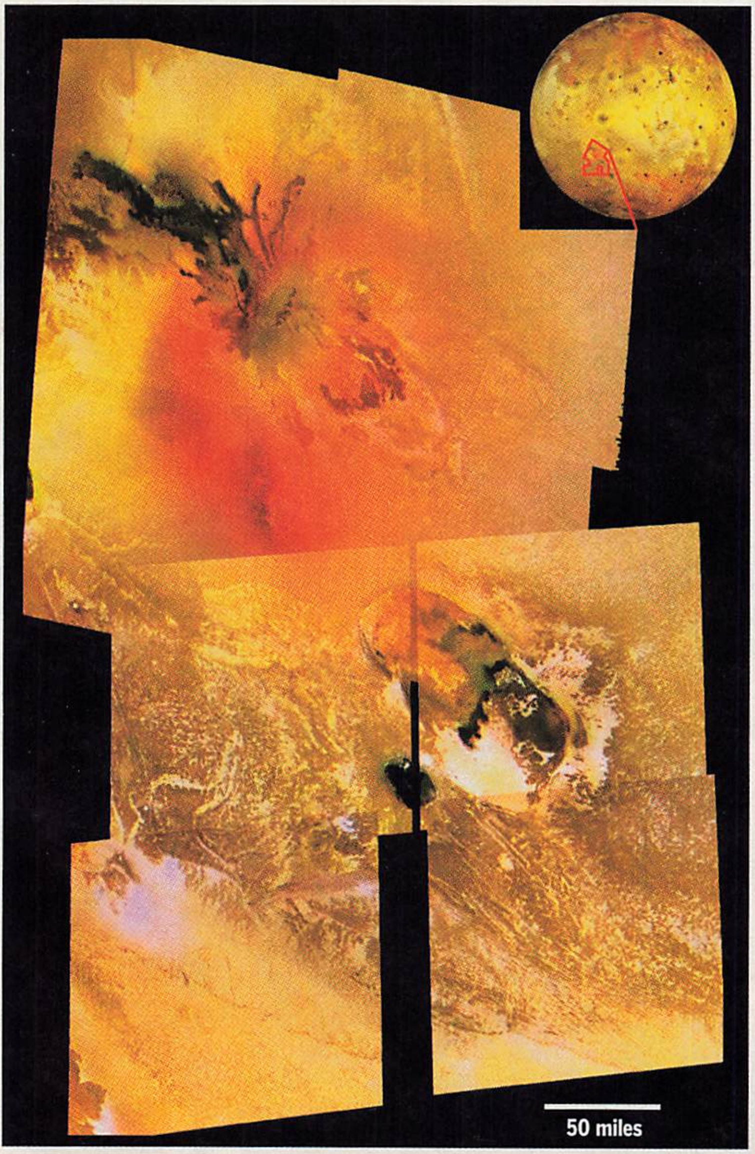
NEWS ABOUT SCIENCE, MEDICINE, AND TECHNOLOGY

HOME REMEDY FOR EARTH

AIR POLLUTION IS A SERIOUS PROBLEM IN MANY parts of the world, but just how serious is often not clear because it costs a lot of money to get accurate readings. Fortunately, Larry St. Clair of Brigham Young University in Utah may have found a quicker, cheaper way to monitor air quality: lichens. Because lichens mop up pollutants like sponges, St. Clair decided to see if they did so in a manner that reliably reflects the level of contaminants in their surroundings. His team harvested lichens from sites in four states—Arizona, New Mexico, Wyoming, and Colorado—that are plagued by copper pollution. The researchers then assayed concentrations of copper in the





Galileo Makes Its Last Stand

THE *GALILEO* SPACECRAFT, WHICH HAS BEEN DILIGENTLY orbiting Jupiter for seven years, will soon meet a fiery demise. Yet even as its fuel dwindles and its instruments begin to fail, *Galileo* continues to surprise scientists.

In November *Galileo* made its closest pass yet to Jupiter, skimming 89,000 miles above the planet's upper cloud layer. This approach—the 34th loop around Jupiter—sent the probe deep inside the planet's powerful radiation belts. A barrage of protons temporarily immobilized *Galileo's* tape recorder, but engineers managed to recover data about Jupiter's magnetic field and its thin rings. During that same orbit, *Galileo* made a close flyby of Amalthea, a ruddy, potato-shaped moon. Amalthea's gravitational tug on the spacecraft was far weaker than expected. Torrence Johnson, *Galileo* project scientist at NASA's Jet Propulsion Laboratory, says the 170-mile-wide body is probably "a very porous rubble pile, made of light rock mixed with ice and a fair amount of empty space." NASA has also just released five new images of giant red-and-black volcanoes and lakes of sulfurous lava on Io, a hellish satellite the size of Earth's moon.

In September *Galileo* will plunge into Jupiter's atmosphere, a strategy devised to prevent the spacecraft from contaminating Europa, the icy satellite that some scientists say could harbor life. But the probe will keep working to the end, gathering data about Jupiter's magnetosphere before burning up like a shooting star.

—*Maia Weinstock*

Jupiter's moon Io (top) is the most volcanic world in the solar system. *Galileo* images show flows of dark lava and colorful sulfur ash from the volcano Culann Patera (middle). White patches might be sulfur dioxide snow (bottom right).

PHOTOGRAPHS: TOP, COURTESY OF LARRY ST. CLAIR/BRIGHAM YOUNG UNIVERSITY; BOTTOM, COURTESY OF NASA/JPL.

lichens and compared the results with those acquired using mechanical monitoring devices. As pollution detectors, the lichens were as accurate as the best equipment available. St. Clair says the lowly lichen could revolutionize biomonitoring. He envisions transplanting the organisms to keep watch over highly polluted areas all over the world: "There's no reason we can't extend the predictability of the system to some of the other pretty nasty things that are being put into the air." *—Rachael Moeller Gorman*

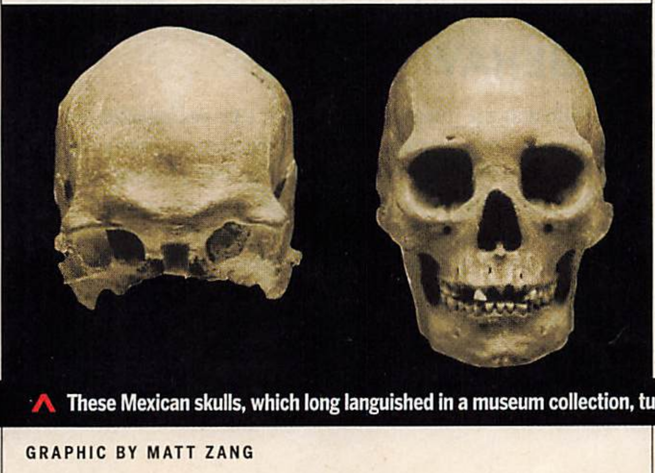
Lichens—symbiotic arrangements of bacteria and algae—contain a hidden record of air pollution.

A NEW LOOK FOR THE FIRST AMERICANS

A SET OF ANCIENT SKULLS UNEARTHED in central Mexico's Teotihuacán Valley, found at construction sites in the rapidly growing Mexico City region, are rewriting the history of human colonization in North America. Geologist Silvia Gonzalez of Liverpool John Moores University in England recently analyzed four of the skulls with help from colleagues at the National Museum of Anthropology in Mexico City, where the bones are housed. She was amazed to find that one of them is 12,700 years old, 700 years more ancient than any human remains ever before found in North America.

That skull, known as Peñon III Woman, has a long, thin shape, dramatically unlike the short, broad form of previous Mexican remains and of today's Native Americans. Most anthropologists believe Native Americans are all descended from a single population that arrived from Siberia. But the Peñon III skull, along with others in the museum collection, does not seem to be related to the Siberian travelers. Rather, they resemble Japan's indigenous Ainu people. Gonzalez believes relatives of the Ainu were part of another, previously unknown wave of immigration that originated in Japan, swept across the Bering Strait, then moved down the west coast of North America and into central Mexico.

Anthropologists have found remains of one modern narrow-headed population, the Pericus, that lived in Baja, California, until going extinct in the 18th century. Gonzalez plans a return trip to Mexico this month to collect DNA samples from Peñon III Woman. She will compare those samples with DNA from Pericu bones to see if the two populations are related. "We need to discard the hypothesis that it was just one massive migration into America. The picture is much more complicated," she says. *—Kathy A. Svitil*

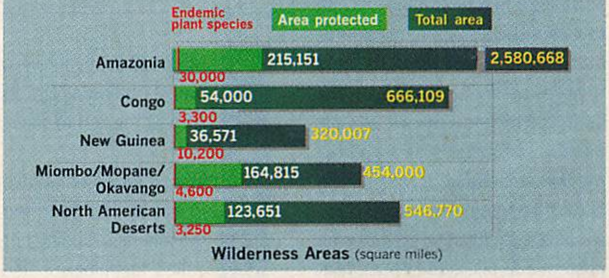


These Mexican skulls, which long languished in a museum collection, turn out to be more than 12,000 years old.

PHOTOGRAPHS COURTESY OF NATIONAL MUSEUM OF ANTHROPOLOGY, MEXICO.

WHERE THE WILD THINGS ARE

Despite all the ways humans reshape the land, roughly half our planet remains wild. Using on-the-ground measurements and satellite imagery, researchers sponsored by Conservation International—a nonprofit environmental organization in Washington, D.C.—identified 37 wilderness regions that cover 54 percent of Earth's land. These regions are defined as patches larger than 6,200 square miles that retain at least 70 percent of their original vegetation and that harbor fewer than 15 people per square mile. Better still, 17 percent of the world's plant species are concentrated in five high-biodiversity wilderness areas that cover just 6 percent of Earth's surface. These sparsely populated areas are obvious targets for conservation efforts, yet the vast majority of their area is not protected. Gustavo Fonseca, executive director of the Center for Applied Biodiversity Science at Conservation International, worries about threats from mining, grazing, deforestation, and other human activities. "It's now a question of whether we can get ahead of development trends and establish protected areas and more benign land uses," he says. *—Rachael Moeller Gorman*



Wilderness Areas (square miles)

DUSTING FOR NEW PLANETS

THE HUNT FOR PLANETS AROUND OTHER STARS JUST GOT EASIER. Alice Quillen of the University of Rochester and undergraduate Stephen Thorndike of Alfred University, also in New York, have found a way to detect worlds too small or slow-orbiting to show up in current surveys. This method has revealed what may be a Neptune-size body circling Epsilon Eridani, one of the closest sunlike stars.

Astronomers have identified more than 100 planets orbiting stars outside our solar system, primarily by monitoring the way a planet's gravity tugs its star back and forth. That technique most readily picks up Jupiter-size planets in fast, Mercury-like orbits, objects unlike anything in our solar system. A newer approach, looking for the shadow of a planet passing in front of its star, has similar limitations. Quillen and Thorndike instead study subtle gravitational disturbances in the dust rings that surround many stars less than a billion years old. As a test, the researchers observed infrared emissions from the faint dust around Epsilon Eridani and compared them with computer simulations of clumping patterns. Their results indicate a possible planet approximately the mass of Neptune—the smallest yet seen around a sunlike star—orbiting every 280 years. That period is similar to the 164-year orbit of the real Neptune. "We were totally surprised," Quillen says.

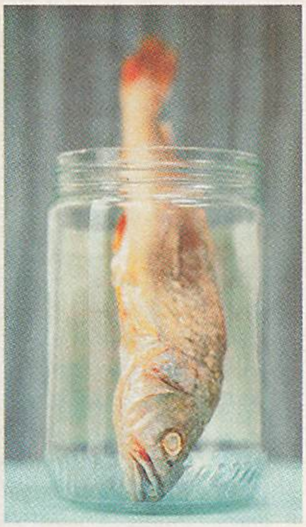
Previous studies have revealed a Jupiter-mass planet in a roughly Jupiter-like orbit around Epsilon Eridani. If the new planet checks out, Epsilon Eridani starts to look a lot like our solar system. Quillen wants to use NASA's new Space Infrared Telescope Facility to get a clearer view of the dust ring. Earth-like planets, however, remain beyond the limits of today's searches. *—Maia Weinstock*

GRAPHIC BY MATT ZANG

DON'T BE A SPINELESS LOVER

THE BRAIN MAY BE THE ORGAN where sexual desire begins, but it takes a spine to finish the job. Neuroscientists Lique Coolen and William Truitt of the University of Cincinnati have pinpointed the neural circuitry that triggers ejaculation—in the lower spinal cord.

Coolen used toxins to disable neurons in the lowest quarter of male rats' spinal cords and then put the rats in cages with females. The toxin-addled males behaved exactly like normal rats, but they never ejaculated. "The action is controlled in the spine and not the brain; it's essentially a reflex," Coolen says. But ejaculation is a complicated process all the same. The trigger cells in the spine seem to generate and respond to a unique combination of neurotransmitters, which allows the cells to act as messengers between the brain and the reproductive organs. Members of Coolen's lab are studying these chemical signals in the hope of harnessing them to treat the ejaculatory dysfunction that, at some point, affects one in three men. "But discussing any clinical applications at this point is probably . . . premature," Coolen says. *—Jocelyn Selim*



FISH REALLY *IS* BRAIN FOOD

BREAK OUT THE TARTAR SAUCE AND START FRYING UP THE COD: PASCALE Barberger-Gateau of Victor Segalen Bordeaux University in southwestern France and his colleagues report that people who eat at least one serving of seafood a week are less likely to develop dementia later in life.

The researchers gathered diet information from 1,674 dementia-free senior citizens and then spent seven years checking up on the subjects and testing their mental capacities. People who ate more seafood than average—at least one serving a week—had a 30 percent lower risk of developing dementia than those who followed a diet relatively low in fish. Barberger-Gateau suspects the polyunsaturated fatty acids in fish reduce inflammation in the brain and may aid neural regeneration. His team also discovered that dementia occurs less often among highly educated people, a conclusion supported by other studies. Many scientists have hypothesized that exercising the brain helps reduce the mental effects of aging, but there may be a second influence at work. More highly educated people tend to eat more fish, both because they can afford it and because they are more likely to adhere to dietary recommendations. *—Rachael Moeller Gorman*

LANDMARKS

March 10 375th anniversary of the birth of Italian physician Marcello Malpighi, founder of microscopic anatomy. He was the first to see red blood cells and capillaries.

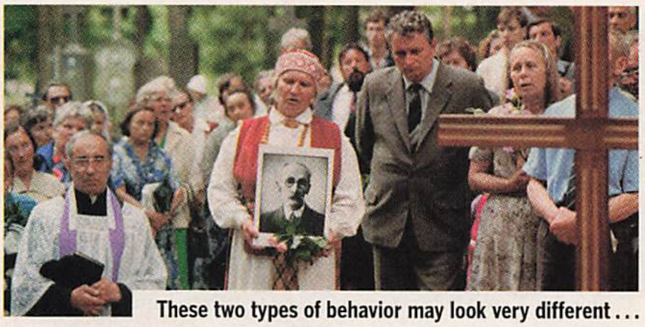
March 13 270th anniversary of the birth of Joseph Priestley. He identified numerous gases in the atmosphere, including nitrogen, ammonia, and what he called "dephlogisticated air." We know it as oxygen.

March 14 100th anniversary of the founding of the first national bird sanctuary in the United States, established on Pelican Island off the east coast of Florida.

TRIBUTES

Died Charles Rosen, 85, on December 8, 2002. He oversaw the creation of "Shakey," a 1966 robot programmed to perform simple tasks like moving a box around a room. The project was the basis for software that ran the Mars rover, *Sojourner.*

Died Grote Reber, 90, on December 20, 2002. In 1937 he built the first radio telescope in his backyard. Later radio observations led to the discovery of quasars and the apparent afterglow of the Big Bang.



These two types of behavior may look very different . . .

but funeral rituals seem to be generic to all cultures.

CRACKING THE HUMAN BEHAVIOROME

DARRYL MACER, A BIOETHICIST AT the University of Tsukuba in Japan, wants to understand the human psyche as thoroughly as we understand human DNA. So he is trying to organize a Human Behaviorome Project that will quantify the things we do when we put our genes into action: every personal, social, and cultural behavior that makes us human.

Macer came up with the plan after asking 6,000 people in 12 countries to provide their views on moral dilemmas such as whether it is acceptable to abort a Down's syndrome baby or grow genetically engineered tomatoes. Regardless of the dilemma presented, the number of solutions proposed was never more than about 50. That result led Macer to conclude that the number of human ideas is finite, and hence could be tabulated and mapped.

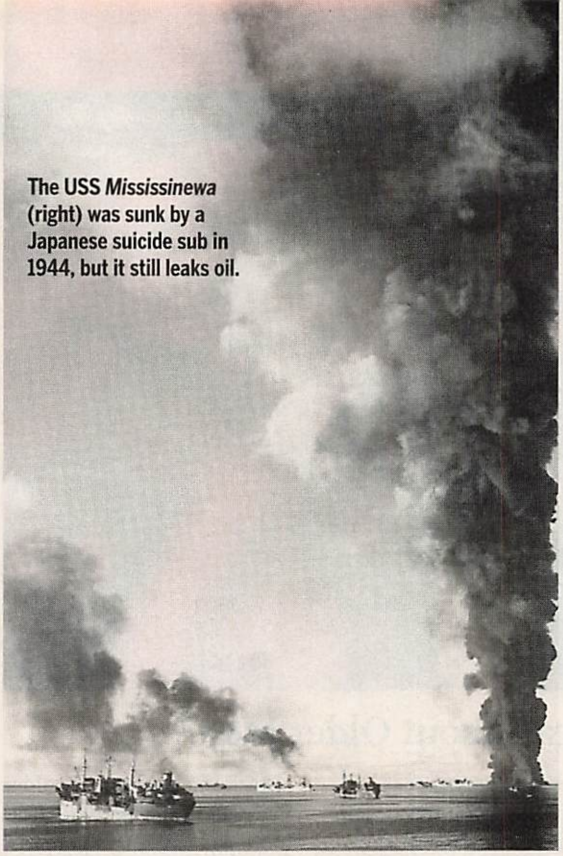
The same fundamental ideas—grieving rituals for the dead, a social hierarchy, group warfare, and punishment systems—are found in all human societies and in many animal ones, too, Macer notes. "There are social customs that are unique, such as eating the hearts of your enemies in battle, but underlying them are common principles," he says. He suggests that a database of human values could clarify the diversity of behavior in different cultures and help show how genetic and social factors influence ideas. Macer invites the public's input: www.biol.tsukuba.ac.jp/~macer/mentmap.htm.

—Josie Glausiusz

PHOTOGRAPHS: CLOCKWISE FROM TOP, OOTE BOE/NONSTOCK; NATHAN BENN/CORBIS; DAVID TURNLEY/CORBIS.

The Oils of War

MICRONESIANS, MELANESIANS, AND Polynesians are still paying for battles fought in their backyard during World War II. Researchers at the South Pacific Regional Environment Programme in Samoa report that fuel and toxic chemicals are still leaking from the more than 1,000 military and cargo vessels from Japan and the United States that sank in this region between 1941 and 1945. Two summers ago a tropical storm rocked the USS *Mississinewa*—an oil tanker torpedoed near Micronesia's Ulithi Atoll—spilling 24,000 gallons of fuel and halting local subsistence fishing. Officials in the area report other fish kills and oil deposits washing up onshore. A cleanup will most likely require international assistance. Siphoning off the oil from the USS *Mississinewa* alone would cost up to $6 million, says Sefanaia Nawadra of the South Pacific Regional Environment Programme. —*Josie Glausiusz*



The USS *Mississinewa* (right) was sunk by a Japanese suicide sub in 1944, but it still leaks oil.

Science Surfing

Tour Earth's Biodiversity Hot Spots
(www.biodiversityhotspots.org)
Drop in on 25 wilderness locations, which support nearly 35 percent of all terrestrial vertebrate species.

Make a Bet on the Future
(www.ideosphere.com)
Trade shares that represent the odds of possible events—such as the discovery of an Earth-like planet by 2005.

Follow in the Footsteps of Lewis and Clark
(nd.water.usgs.gov/lewisandclark)
Celebrate the 200th anniversary of this landmark journey of exploration.

See How Your Taxes Support Science
(www.science.gov)
Browse through an exhaustive index of federally funded research.

DANGEROUS LANDSLIDES ATOP EARTH'S CORE

TWO THOUSAND MILES UNDERGROUND, GIANT AVALANCHES ARE reshaping Earth's inner landscape, says physicist Richard Muller of the University of California at Berkeley. Such turmoil might cause the episodic vanishings and reversals of Earth's protective magnetic field.

Muller has studied the dynamics of Earth's outer core, a molten, iron-rich mass whose circulation powers our planet's magnetic field. As the outer core slowly cools and crystallizes, lighter minerals such as sulfur and silicate get left out. "These minerals drift up and fall like snow, forming inverted mounds," Muller says. The biggest heaps might accumulate for a million years and rise 300 feet high. If such a pile collapsed, it could alter currents in the core and temporarily shut off Earth's magnetic field. "When the field turns back on, it can have the same polarity or the opposite one. This could explain geomagnetic reversals," Muller says.

A large asteroid impact could trigger a wave of avalanches across the core, Muller suggests, leading to a prolonged magnetic shutdown. Inner disruption could also send a plume of magma rising toward the surface. That link might explain why the giant impact of 65 million years ago, when the dinosaurs went extinct, coincided with huge volcanic eruptions in India. The GRACE satellite, now mapping Earth's gravitational field, could confirm Muller's hypothesis. "If GRACE sees gravitational changes and there is no surface activity that can account for them, they might be from avalanches," he says. —*Kathy A. Svitil*

'The visible world is the invisible organization of energy'

—Physicist Heinz Pagels

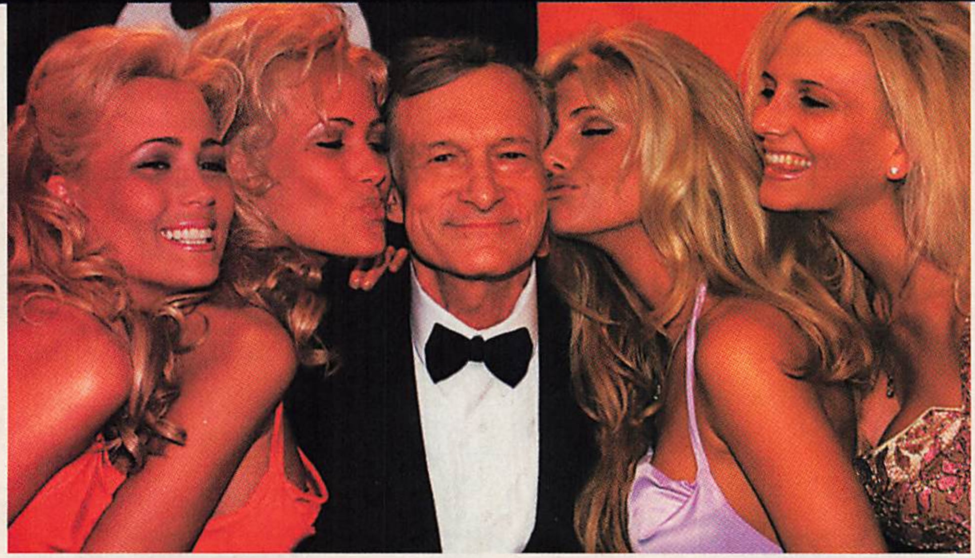
TUNING IN TO SACRED SOUNDS

PREHISTORIC ROCK ART AT MANY SITES, FROM DEEP FRENCH CAVES TO North American canyons, typically appears in inaccessible locations. Steven Waller, a biochemist and rock-art acoustician in California, thinks he knows why. After analyzing more than 100 sites on three continents, he found that the places where the art was made tend to have particularly strong sound reflections. "Many legends explain echoes as supernatural spirits, so maybe the artists were going into caves seeking the spirits," Waller says. Ancient artists may also have chosen the subjects of their paintings based on images suggested by acoustic ricochets. Echoes of hand claps sound like hoofbeats, Waller says, and hoofed animals show up frequently in rock art. "It makes a kind of audiovisual effect: If you yell at the painted image, it will speak back to you," he says. Waller hopes his discovery will influence preservation efforts, which often ignore the acoustic impact of changes made to protect an area or to improve access. "The city of Albuquerque is proposing a six-lane highway right through the heart of Petroglyph National Monument in New Mexico," Waller says. —*Fenella Saunders*

Rock art in California's Coso Mountains is in a reverberating location.

PHOTOGRAPHS: TOP, USNI PHOTO ARCHIVE; BOTTOM, COURTESY OF STEVEN WALLER.

It's nothing personal, Hugh. The women are just impressed by the persistence of your male signaling display.



What's So Great About Older Men?

ERIC CLAPTON, PAUL McCARTNEY, and Michael Douglas prove that women do not mind hitching themselves to drastically older men. Stephen Proulx, a zoologist at the University of Toronto, has developed an evolutionary model that makes this behavior easier to understand: It's not just about money, but it's not just about genes either.

The prevailing biological theory for matches between younger women and older men is that mature males have proved the superior fitness of their DNA by the mere fact that they are still around. Using game theory and computer modeling, Proulx argues instead that age-divergent coupling is rooted in appearance. Nearly every animal uses some form of signaling display, such as a peacock's plumage or a buck's antler battles. Such displays cost the animal a lot of energy, and become increasingly hard to maintain with age, so a good display by an elderly male is a more reliable indicator of genetic quality than a comparable show by a younger, stronger one.

In human terms, an older man flaunting a new Porsche is more persuasive to a potential mate than a young man making a similar display. The show of wealth tends to reflect the fitness over time of the older man; from a young upstart, it might mean he has traded long-term for short-term success. "It loosely translates to a young guy not blowing his college savings on a sports car, while a 65-year-old figures, 'What the hell,'" Proulx says. "I call it the 'Revenge of the Nerds' effect." *—Jocelyn Selim*

BEYOND BREATHALYZER

WHEN POLICE IN THE UNITED States pull over a driver on suspicion of "driving under the influence," about half the time that influence turns out to be illegal drugs. Proving the presence of drugs requires a blood test that takes weeks to analyze. So LifePoint, a medical diagnostics company in California, has developed a way to test for up to 10 drugs in five minutes by examining saliva.

"Basically your saliva is made from plasma, the liquid portion of blood," says Linda Masterson, president of LifePoint. Measuring the drug levels in spit, along with its acidity, can provide an accurate read of the dose present in a person's bloodstream. LifePoint's device uses a pump to draw saliva into 10 columns, each containing an antibody that reacts with a specific drug. If any of that substance is present, the antibody binds to the drug and releases a fluorescent compound. This process, invented by the Navy, was used to search for airborne particles from chemical weapons during the Gulf War. LifePoint's Impact system has undergone pilot trials in 10 countries and is now being tested in the United States. *—Fenella Saunders*

'Democracy might therefore… in a sense be termed that practice of which science is the theory'

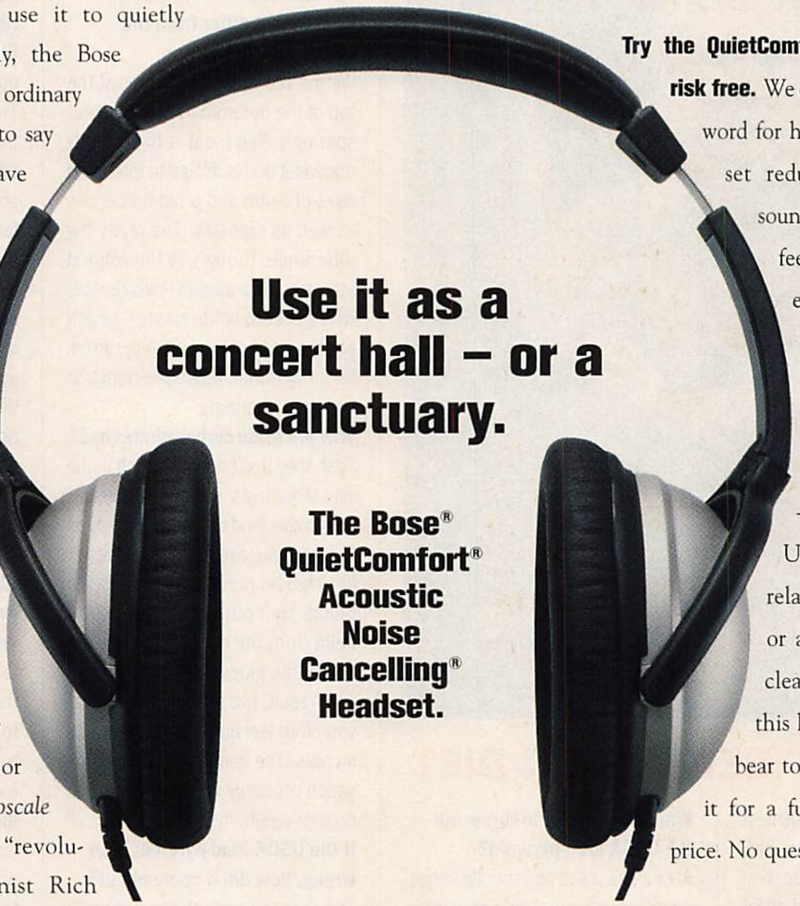
—Biologist and philosopher Joseph Needham

Ask the Wizard

How do X-ray machines work? *ASHLEIGH, GRIMSBY, ONTARIO*

Wallace Tucker, science spokesman for the Chandra X-Ray Center at the Harvard-Smithsonian Center for Astrophysics, replies: The X-ray machines used for medical diagnosis and airport security consist of an X-ray source at one end and film or an electronic X-ray detector at the other. The source is a tube in which electrons bombard a target made of heavy atoms such as tungsten, generating X rays. The object to be examined is placed between the source and the detector. Bones or metallic objects are denser than body tissue, so they absorb or scatter the X rays more effectively, creating a shadow. In a computed tomography (CT) scan, an X-ray machine makes images from many angles and combines them into a three-dimensional picture. Astronomers use X-ray telescopes to study exploding stars, black holes, and active galaxies. These devices do not contain an X-ray source, of course. Instead, they use mirrors to collect and focus the faint emissions from cosmic sources onto an electronic detector. These telescopes are also sometimes used to study the interior of objects lying between the source and the detector, when X rays from a bright, distant galaxy pass through an intervening galaxy. Atoms in the more proximate galaxy will produce an X-ray shadow, which can reveal the composition of the intervening galaxy.

PHOTOGRAPHS: TOP, AP PHOTO/LAURENT REBOURS; BOTTOM, LESTER LEFKOWITZ/CORBIS.



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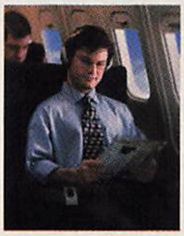

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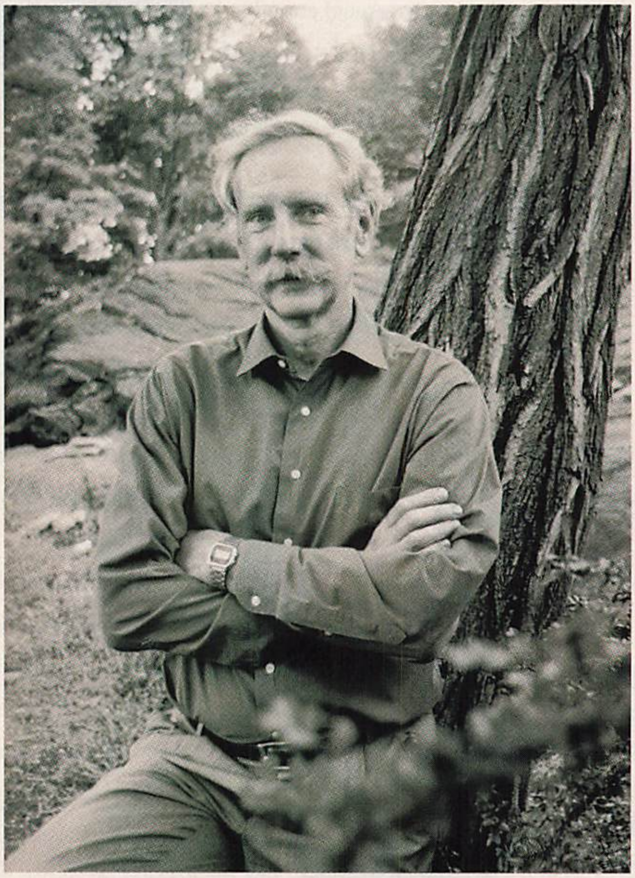

PHOTOGRAPH BY AMANI WILLETT.

A VOICE OF REASON ON DIET

Trying to figure out the healthiest way to eat keeps getting more baffling. Recent news stories question the conventional wisdom that all fat is bad for you. Meanwhile, the old guidepost—the U.S. Department of Agriculture's food pyramid—has come under increasing fire. Walter Willett, chairman of the nutrition department at the Harvard School of Public Health, wants to throw out the USDA guidelines entirely and replace them with a science-based Healthy Eating Pyramid. A new study of 100,000 people shows that switching to Willett's dietary scheme—which emphasizes whole-grain foods and plant oils—cuts the risk of cardiovascular disease in men by 39 percent and in women by 28 percent. Willett, who put himself through college by selling home-grown vegetables, discusses the latest findings on nutrition with associate editor Josie Glausiusz.

Why do you want to throw out the USDA food pyramid?

At best, it's a lost opportunity to help people make important changes in their diets. At worst, some people are likely to die from following the USDA pyramid because they will be eliminating healthy fats, such as liquid vegetable oils, that actually reduce the risk of heart disease. The unhealthy fats are the animal fats, mainly from red meat and butter, which are high in saturated fats; even worse are the trans-fats from partially hydrogenated vegetable oils found in deep-fried fast foods.

What does your Healthy Eating Pyramid look like?

At the base, we put regular physical activity and weight control. The next layer up emphasizes whole-grain, high-fiber healthy carbohydrates and healthy fats such as liquid vegetable oils and foods made from avocados and nuts. I also encourage eating an abundance of fruits and vegetables. Nuts and legumes are good sources of protein for vegetarians, but adding in fish and moderate amounts of poultry and eggs can also be perfectly healthy.

How does it differ from the USDA guidelines?

We put red meat and butter at the top of the pyramid as things to eat sparingly. Red meat is high in saturated fat and is related to increased risks of colon and prostate cancer, as well as diabetes. The really big difference, though, is the refined starches and sugars—white rice, white bread, white pasta—which are the base of the USDA pyramid. In our pyramid, those are things to be eaten sparingly.

Why are these carbohydrates bad?

First, they don't provide much in the way of nutrients. Second, refined carbohydrates tend to cause rapid spikes of blood glucose. The body doesn't like high amounts of glucose in the blood, so it pumps out a lot of insulin from the pancreas, and that brings the glucose crashing down. As a result, two or three hours later you often feel hungry. That tends to increase the frequency of snacking, which probably makes it harder to control weight in the long run.

If the USDA food pyramid is so wrong, how did it come about?

The Department of Agriculture's first constituency is agribusiness: Big Beef, Big Milk, Big Sugar, Big Grain. Yes, the department has some interest in nutrition, but it's going to be extremely difficult for them to say, "Eat less red meat." The low-fat emphasis is also convenient. The meat people, the dairy people, the baking people can all say, "We've got a low-fat version, and this is supported by the pyramid," which it is.

High-fat, low-carb diets are all the rage right now. Do they stand up to scientific scrutiny?

They seem to work better for controlling weight than the opposite, low-fat, high-carbohydrate diet. If you're going to be eating a high amount of fat, however, it's doubly important to make that healthy fat. I don't think this idea of eating all the red meat and cheese you want is a good diet. Interestingly, carbohydrates are not an essential part of the human diet. We need glucose to fuel the brain, but we can generate enough from protein and fat in the diet. The Greenland Eskimos have had a very low carbohydrate intake, and they seemed to do all right from that.

Almost one-quarter of Americans are obese. Why?

We've created the great American feedlot. Farmers have known for thousands of years that if you want to fatten up an animal, you put it in a pen so it can't run around and you feed it lots of grains. People are not too different. The vast majority get far too little physical activity. We have an abundance of cheap food and a food industry that spends huge amounts of money using every trick they can to get us to eat more of it.

An extended version of the Discover Dialogue is available at www.discover.com.

SURGERY BY SUNLIGHT Jeffrey Gordon, a mechanical engineer at Ben-Gurion University of the Negev in Israel, and his colleagues have created a solar-powered tool that could perform laserlike surgeries at one-hundredth the cost. The device collects sunlight in a mirrored dish, concentrating it by a factor of 10,000, and then transports the beam to an operating room through an optical fiber. A six-minute-long exposure can excise almost one-fifth of a cubic inch of tissue, enough to kill most cancerous tumors. Gordon came up with the idea while visiting his university hospital, which has two laser-surgery units that cost $130,000 each. He realized solar energy could provide an affordable alternative and created his sun-driven prototype for $9,000; future versions should cut the cost to $1,000. He has demonstrated clean incisions on chicken breasts and livers and is beginning to test solar surgery on live rats. The device cannot match the collimation of a laser, and it depends on sunshine. "But in most Sunbelt climates, there are at least 250 days out of the year when it's viable," Gordon says. *—Lauren Gravitz*

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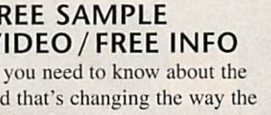

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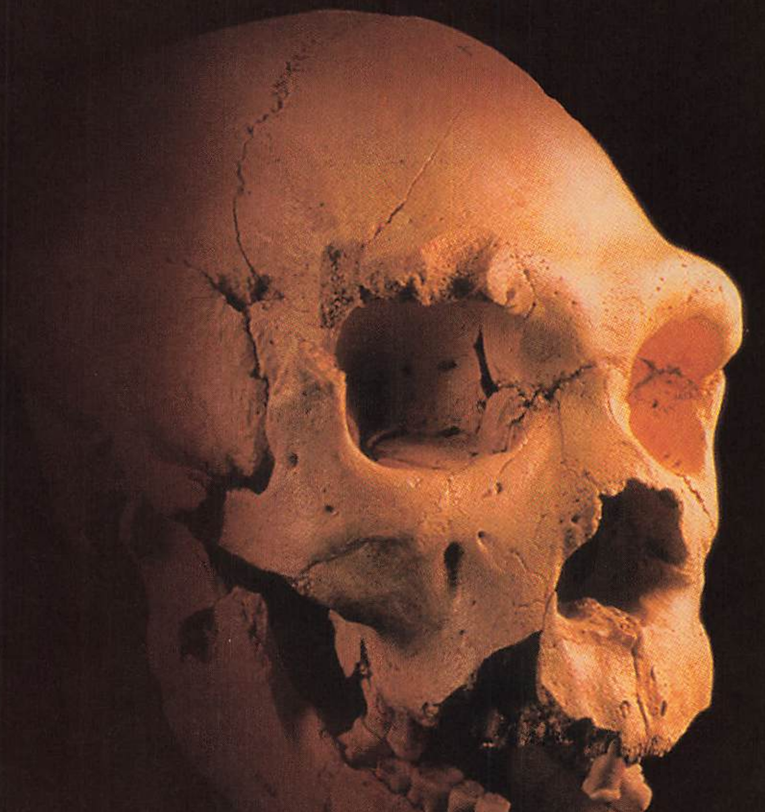

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by steven johnson

Music of the Swarms

Who needs musicians when computers can think like bees?

"I REALLY LIKE TO SWARM IN HARMONY SPACE," Tim Blackwell says as he stares at a few brightly colored shapes darting across a computer monitor. We're sitting in the small studio in Blackwell's house in the northwest London community of Harrow on the Hill. Blackwell is a computer-science researcher and a jazz musician, and he looks the part: shaggy shoulder-length hair and an affable demeanor. As we watch the shapes on the screen, Blackwell plays a series of chords on a music keyboard at his side. With each chord change, the shapes swoop together toward a new spot on the screen, like a flock of birds suddenly spotting a food source. It's a delightful effect, like a musical score in which all the notes have come alive and started dancing across the sheet music. "You could really lose a whole day just playing with this," I say. Blackwell laughs. "More like a whole year," he says.

For almost as long as we've had digital computers, enterprising programmers have been trying to teach them how to play music. Perhaps the most challenging remaining hurdle is the spontaneous back-and-forth flow of improvisation. Machines are quick to learn when it comes to rolling out standard chord progressions and following predictable rhythms. But they turn out to be lousy at riffing, precisely because riffing is a much more chaotic sort of pattern, one that relies on intuition more than structure. A computer might be able to convincingly replicate the bass line for Jimi Hendrix's "Are You Experienced?" but a machine-simulated version of a Hendrix solo would be a dead giveaway. The problem gets more complicated when the music in question is "free improv," a contemporary movement—inspired by the "free jazz" recordings from the 1960s of Ornette Coleman and Cecil Taylor—in which all the musicians play improvised solos at the same time, following each others' evolving cues rather than a pre-existing score.

As daunting as it sounds, free improv may yet become a part of the computer's musical repertoire, thanks to sophisticated software programs like the one developed by Tim Blackwell. The key to this breakthrough does not lie in teaching the computer how to think like Coltrane. The key is teaching it to think like a bee. Bees, you see, display an increasingly influential behavior in their everyday interactions. They swarm. In other words, they move in loosely organized groups that form higher-level patterns without relying on a central leadership or master plan. Flocks of birds show similar bottom-up organization.

In June 2001, Blackwell, a computer-science graduate student at University College London, was looking for a master's degree project. He started to think about the connection between flocking animations and his own experience as a free-improv saxophonist. So he contacted Peter Bentley, a professor at the college who had already built a name for himself applying biological models to computing. "I've used evolution to generate novel designs or to detect fraud, immune systems to find hackers, or ↘

<>

In Tim Blackwell's computerized "free improv" compositions, the notes sometimes fly together in formation, resembling bird flocks, instead of buzzing around a target like a swarm of bees. The resulting sound is similar to a musical phrase repeated over and over, but with slight variations.

ILLUSTRATION BY LEO ESPINOZA

↗ neural networks to control robots. When Tim came to see me about doing his master's project, I was looking for an interesting application for swarms. As we chatted, we both realized just how similar swarms and jazz musicians are, as strange as it sounds."

Picture a swarm of bees moving toward a summer garden in full bloom. There is structure in that movement, both in the coherence of the group itself and its ability to home in on a specific target. But there is also variation. Swarms of bees don't look like F-14s flying in formation; they look like swarms. This complex behavior, somewhere between order and chaos, derives from relatively simple local rules followed by each bee: Move toward the center of the swarm, avoid colliding with other bees, and follow gradients of scent toward the pollen source. As long as each bee plays by these rules, the swarm will do its magic.

To mirror the swarm behavior of bees, Blackwell and Bentley decided to translate the language of music into a 3-D space, with a dimension each for pitch, duration, and volume. A "particle" moving through that space changes its musical parameters as it changes its position, growing louder, higher pitched, or longer. At any given time, multiple particles explore the space, following the rules of swarm logic: Avoid collisions with other particles, gravitate toward the center of the swarm, and track toward targets that have been defined by the system. Collision avoidance keeps the software from generating too much repetition, such as having the same note played at the same volume by several different particles. Swarm-centering keeps the musical riffs in a coherent zone. For example, you don't want one note that's consistently three times louder than all the other notes.

Targeting may be the most interesting element. A target can be defined by a preexisting score, by a human musician playing in real time with the software, or by another particle swarm. Imagine a flesh-and-blood pianist who begins to play staccato notes in C minor; a particle swarm playing along in real time would move through the musical space toward compatible notes. The swarm wouldn't directly mimic what the human was playing; it would take the general properties of the human-created music and riff off them. "The striking characteristic of the swarm is its sensitive responsiveness," says Robin Higgins, a pianist and singer who has played more than a dozen pieces with the "swarm music." "Like a good improvising partner, it picked up musical structures I gave it."

Blackwell and Bentley have also experimented with a kind of hall-of-mirrors system, in which two particle swarms follow each other's lead: Swarm A conjures up a certain musical palette, which becomes a target for swarm B. The response generated by swarm B becomes a new target for swarm A, and so on. Thus far, the performance that Blackwell and Bentley are most proud of involves precisely this feedback structure but with a twist: two swarms playing off each other, while Blackwell "conducts" by tweaking variables as the composition unfolds.

"In this case, I was periodically fixing swarm B to produce sustained chords," Blackwell says. "I was also changing instruments for swarms A and B—like orchestral sections. Swarm A was always playing melody, and I fixed the interpretation to a small range of beats per minute. This means that swarm B moves toward these targets in a more restricted part of its music space. And then swarm A is attracted to where swarm B is, and so on. The result was an astonishing high-speed chase through music space."

Just as the flight of a bumblebee inspired Rimsky-Korsakov, the flight of virtual swarms may inspire a new generation of composers

It's an arresting image—musical swarms chasing each other through a mathematical space—but what does the music sound like? You can hear the results for yourself at Tim Blackwell's site (www.timblackwell.com). Be forewarned: It's a challenging sound. The closest thing on the pop charts is probably the electronica dabbling on recent Radiohead albums. But it grows on you, particularly if you're already versed in the unstructured play of improvisational music. "I'm not a musician," Bentley says, "but I've worked with them in the past, so I understand how the musical mind works, and sometimes they can find rapture in the most bizarre of noises. But when it comes to swarm music, even my humble musical appreciation abilities are sufficient. The way the notes chase each other, causing cascades of melodies, countermelodies, and harmonies, is wonderful."

To my ears, the swarm compositions, even when judged by free-improv standards, have an unfinished feel to them. Of course, Blackwell and Bentley have only just begun to explore the possibilities of their software. Blackwell thinks it may be most useful as a compositional tool, not as a replacement for the creative process. Just as the flight of a real-world bumblebee inspired Rimsky-Korsakov to write his now-ubiquitous melody, the flight of these virtual swarms may inspire a new generation of composers, creating passages of music that would then be shaped and refined into final renditions. The swarm doesn't write songs; it suggests new avenues to explore.

I find this idea enticing precisely because it swarms in the face of the preconception that computers are there to store our files and record our keystrokes and nothing more. Swarm music suggests that this virtual-stenographer role may be an artifact of computing's early days. Simple digital machines are good at capturing and storing information. Complex machines are good at generating new kinds of information and triggering new connections, even if that information must eventually be polished by humans. What they produce is more launching pad than archive. That's why I suspect the rough-edged quality of the swarm compositions may turn out to be, as they say, a feature—not a bug. Blackwell and Bentley's creations don't yet sound like finished products, but they do sound like a tantalizing place to start. ⊠

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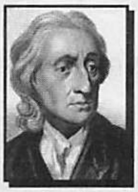
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by claire panosian dunavan

A Killer Raves On

Did this writhing, choking child really have to die?

IN A DARKENED ROOM, A 9-YEAR-OLD BOY lay on a mattress, loosely bound with a cloth rope. Occasionally, he jerked or twitched. Mostly he stared. His breathing was irregular. He was dying.

One week earlier, the boy had arrived fighting and gagging. For several days, his family grieved at his side as he writhed and choked at the mere sight of water. Now that he was so close to death, his parents had left to arrange the funeral.

I witnessed this case of rabies in 1987, when I was a visiting professor of infectious disease at the Aga Khan Medical School in Karachi, Pakistan. The main hospital, with its brick buildings and leafy courtyards, was surprisingly like my own in Los Angeles. But on this day I had traveled to a public hospital on Karachi's outskirts. The facility housed patients with diseases that American doctors had only read about. My host, Dr. Mohammed, had told me the boy's story and invited me to see him.

At first, the child's condition so unnerved me that I had to look away. Still, a voice inside me said, "Look and remember." While I gazed at him, my thoughts turned to a colleague who had visited Mexico a few years earlier. During his stay in a remote village, Matt had noticed a dog behaving oddly. One evening, from out of the darkness, the dog snarled and lunged at his leg. When he undressed, my friend found bloody marks where teeth had punctured his calf.

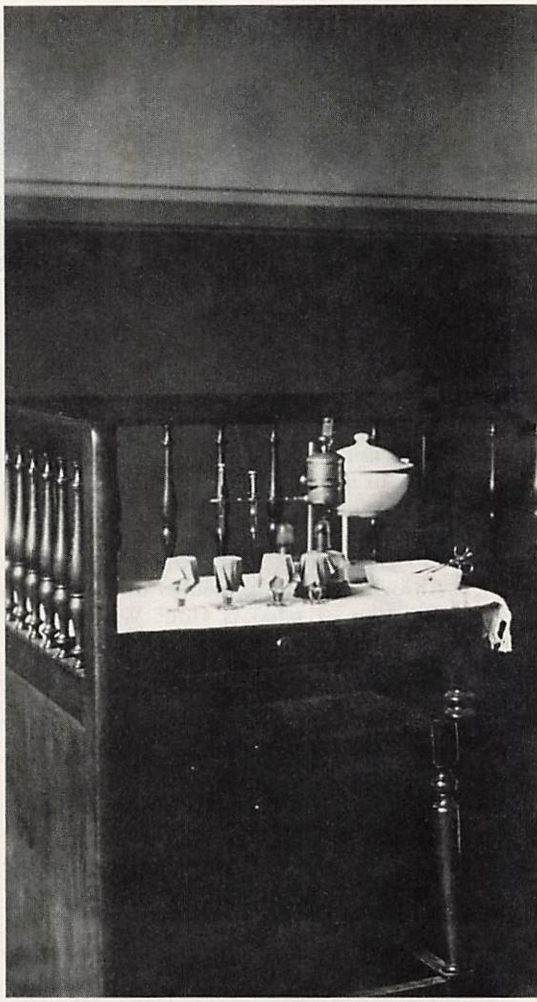
"I instantly knew I had three options," he later told me. "In my halting Spanish, I could try to find the dog's owner and inquire if the dog had ever been vaccinated. Or I could ask to have the dog killed and his brain examined. Or I could get a series of shots." Two days later, Matt was in San Diego receiving rabies antiserum and the first of five rabies vaccinations. Fortunately for him, a new vaccine for rabies had just been approved in the United States. For Americans, the days of painful injections of rabies vaccine in the stomach following unprovoked animal bites were over.

Halfway around the globe, of course, pain was not the issue. For many poor people in India and Pakistan—where thousands of rabies exposures occur every year—treatment was either unaffordable or unavailable. By contrast, improved treatments have helped bring deaths from rabies in the United States down from more than 100 a year a century ago to about one or two every year.

When someone is treated for rabies infection, the goal is to arrest the deadly virus before it reaches the spinal cord or the brain. The pathogen, which commonly gains entry via saliva from a rabies-infected animal, breeds first in local muscle, then advances through long, lanky nerve cells. An initial injection of rabies antiserum (a highly specific antibody culled from rabies-immune humans) can be thought of as a stun gun that slows the virus. Meanwhile, five doses of rabies vaccine given over four weeks are the bullets that complete the counterattack. They do so by kindling enough native antibody to wipe out the remaining invaders.

Before treatment became available, rabies was one of the most uniformly fatal viral infections. As early as the 23rd century B.C., the legal code of the Babylonian city of Eshnunna refers to a disease that was probably rabies. In 500 B.C., the Greek philosopher Democritus recorded an unmistakable description of canine rabies. The word *rabies* itself comes from the Latin verb *rabere*, "to rave," as well as a Sanskrit word for doing violence, underscoring a frequent but not universal feature of the virus's deadly assault.

The two common forms of rabies are "furious" and paralytic, or "dumb." Furious symptoms, such as hydrophobia, delirium, and agitation, reflect invasion of the brain by rabies virus. But in one out of five cases, the disease seems to target only the spinal cord and brain stem. These victims experience confusion and weakness but not the wild, explosive behavior that still prompts straitjackets and padlocked cells for victims in some parts of the world.



In 1892 the renowned physician William Osler described hydrophobia in his medical textbook. "Any attempt to take water," he observed, "is followed by an intensely painful spasm of the muscles of the larynx and the elevators of the hyoid bone [a horseshoe-shaped bone situated at the base of the tongue]. It is this which makes the patient come to dread the very sight of water. . . . These spasmodic attacks may

As a child, Louis Pasteur witnessed a friend's wolf bite being cauterized by the village blacksmith's red-hot iron. Late in life, he developed a rabies vaccine by converting the dried spinal cords of infected rabbits into material that, when injected, produced a protective immune reaction.

PHOTOGRAPHS: LEFT, BETTMANN/CORBIS; RIGHT, DR. GOPAL MURTI/SPL/PHOTO RESEARCHERS.

A man bitten by a mad dog receives a shot to protect against rabies at the Pasteur Institute in Paris, circa 1905 (left). The injection contains material from the virus (seen infecting a cell, above), which arouses the body's immune system.

be associated with maniacal symptoms. In the intervals between them the patient is quiet and the mind unclouded."

Osler's text goes on to state that rabies victims rarely injure attendants during their violent episodes, although they may "give utterance to odd sounds." Mercifully, hydrophobia usually gives way to deeper unconsciousness within three or four days. Soon after, organs fail and the heart stops.

LEAVING THE WARD, DR. MOHAMMED AND I headed for a nearby lounge where we could talk and drink tea. "The boy liked dogs," Dr. Mohammed said quietly as we walked. "It's almost certain he was infected by a dog." I had seen many street dogs in the slums of Karachi, including a few that were sick and whimpering. How easy it would have been, in an impulsive gesture, to reach out to one of them.

Of course, many other animals contract and transmit rabies. Since the 1980s, the silver-haired bat and its kin, the eastern pipistrelle, have been the source of roughly two-thirds of all human rabies cases in the United States. Other susceptible mammals include wolves, foxes, coyotes, cats, skunks, raccoons, and even horses and livestock.

Most human victims sicken within three months of exposure to rabies, but sometimes infections remain dormant for a year or more. Once symptoms begin, however, the die is cast. Over the next one to three weeks, the condemned patient sinks as the virus relentlessly moves from muscle to nerve to spinal cord or brain.

Ancient healers espoused an array of immediate postexposure antidotes, from caustics and cupping to applying a poultice of goose grease and honey. In the first century A.D., Celsus, a Roman physician-naturalist, recognized that saliva transmitted rabies and recommended sucking or burning suspect wounds. Eighteen hundred years later, William Osler's suggestions were surprisingly similar: careful washing, chemical cauterization, and keeping the wound open for several weeks.

Osler did not know of Louis Pasteur's landmark research, conducted just a few years earlier. Pasteur had reported experiments leading to the world's first animal rabies vaccine. He wasn't planning to use the vaccine on a human until he learned of a desperate case: a 9-year-old boy from Alsace bitten 14 times by a rabid dog. Of his next action, Pasteur wrote: "The death of this child seemed inevitable, and I decided, not without lively and cruel doubts . . . to try in Joseph Meister the method which has been successful in dogs. Consequently, on July 6 at 8 in the evening, 60 hours after the bites, in the presence of Doctors Vulpian and Grancher, we inoculated under a skin fold in the right hypochondrium [upper abdomen] of the little Meister a half syringe of the [spinal] cord of a rabid rabbit preserved in a flask of dry air for 15 days." After 12 more injections, it was time to watch and wait. Joseph Meister never developed rabies.

Two 9-year-olds—one in modern Pakistan, one in 19th-century France. One was a rabies victim, the other a rabies survivor. Today an updated form of Pasteur's remedy saves countless lives, yet every year 40,000 to 70,000 people die for the lack of it. If the 19th century's greatest microbiologist knew of these ongoing 21st-century tragedies, what would he say? ☒

The case described in Vital Signs is based on a true story. Some details have been changed to protect the patient's privacy.

by karen wright

The First Earthlings

Geologists and biologists know where to look for the earliest life—but the rocks are hard to read

FOR TODAY'S CIVILIZED WORLD, WITH ITS DOT-coms, sitcoms, ATMs, and ATVs, the first 3.5 billion years of life on Earth are a bit of an embarrassment. It was only a few hundred million years ago that trilobites prowled the seas. More primitive life subscribed to two or three basic lifestyles: algal mat, spineless worm, or bacterial blob. Before that, in the Archean Eon more than 2.5 billion years ago—well, that kind of life is what Lysol is for.

Scientists, of course, see it differently. "Almost everything of any biological importance happened back in the Archean," says Andrew Knoll of Harvard University, author of the upcoming book *Life on a Young Planet.* Soon after the infant Earth cooled down, he says, primeval microbes began processing essential elements—carbon, sulfur, and nitrogen, among others—that allowed for the eventual emergence of higher life-forms, including us. To this day, says Knoll, bacteria still do the biosphere's heavy lifting. "We just sit back and live off the fruits of their labors."

Folks like Knoll would like to know whom to thank for those first trophic cycles. But in the quest to identify Earth's earliest life, geology can look a lot like biology. It's not always easy to tell the dead organisms from the dead ends. One of the few things experts all agree on is where to conduct the search: in the three far-flung provinces that host the world's most ancient sedimentary rocks. Deposits in Australia, Greenland, and South Africa offer a cryptic view of the earth's surface as it was between 3.2 billion and 3.8 billion years ago. The deposits are made up of layers of accumulated particles that were later buried, heated, and compressed. Rounded pebbles and smoothed sand grains in the sediments indicate that they were seabeds, so any life they record would be marine.

These stumplike structures, called stromatolites, in Shark Bay, Western Australia, are composed of blue-green algae and their by-products. The first stromatolites appeared some 3 billion years ago. Modern-day stromatolites are also found in the Bahamas and in Florida's Everglades.

PHOTOGRAPH BY JOHN READER/SPL/PHOTO RESEARCHERS.

The oldest fossil of that life comes from a remote desert site in Western Australia called North Pole. The rocks there bear the marks of stromatolites—sizable mounds of mud and minerals trapped or precipitated by microbial colonies living in shallow ocean water. Modern stromatolites grow knee-high in Australia and the Bahamas, and the organisms that build them leave distinctive patterns in the mud pedestal that can't be duplicated by mere geologic manipulation. At North Pole, those

Some of the earliest signs of life are found in ancient rock layers called banded iron formations. The iron was released by underwater volcanoes and precipitated from ocean water more than 2 billion years ago. Today the rock formations supply about 95 percent of the iron used to make steel.

patterns appear in rocks that are almost 3.5 billion years old.

The sediment layers in the North Pole fossils are much finer than those in modern stromatolites, suggesting that much smaller life-forms inhabited them. Even so, there's evidence of a food chain of sorts. The principal architects of stromatolites are photosynthetic. They get their energy directly from sunlight instead of feeding off other creatures. But geochemists found the chemical signature of a microbe that was feasting on dead organic matter, a scavenger of sorts. "We had quite sophisticated ecological communities back then, even if they were just tiny little microbes," says astrobiologist Roger Buick of the University of Washington, who discovered the North Pole stromatolites.

Unfortunately, the vestiges of microbial communities are far more conspicuous than the remains of their individual members. Lacking bones, shells, teeth, and other hard parts, the first Earthlings didn't fossilize well. In the oldest rocks, chemical leftovers may be the only evidence of animation. So it happens that the earliest evidence of life is not a lithic imprint but a skewed ratio of carbon isotopes in a chunk of rock from southwest Greenland. Microscopic globules of graphite in the rock, documented in 1999 by geologist Minik Rosing at the University of Copenhagen, are unusually low in a heavy carbon isotope that gets excluded when inorganic carbon is converted into living material. Rosing thinks the C-13-poor graphite globules might have come from free-living planktonlike organisms that fell to the seafloor when they died. Their remains, he says, are at least 3.7 billion years old.

In 1996 geochemist Stephen Mojzsis, now at the University of Colorado at Boulder, trumped Rosing's find in a report of heavy-isotope depletion in graphite grains from the Isua formation in Greenland and another site on the Greenland island of Akilia. Mojzsis says the grains are 3.85 billion years old—the oldest yet. But his interpretations of both the biological markers and the rock itself have been put through the wringer. One of Mojzsis's former coauthors, geochemist Gustaf Arrhenius of the Scripps Institution of Oceanography, showed how the Isua carbon-isotopic ratio could arise by geologic activity alone, if certain iron minerals in the rock were melted and pressed together over time. He and other investigators also think that the putative sedimentary rocks are actually igneous formations that have been severely transformed by heat.

A cutaway of a stromatolite fossil reveals layers of sediment and calcium carbonate. Blue-green algae secreted the calcium carbonate, which preserved the structure.

PHOTOGRAPH BY SINCLAIR STAMMERS/SPL/PHOTO RESEARCHERS.

Thus, rocks of advanced vintage seem to confound even the most basic geologic distinction: igneous, metamorphic, or sedimentary? "These rocks have been buried and cooked at least three times," says Buick. "They've been severely squashed and strained and tied in knots at least three times too. Then they sat around for at least a billion years and got polished by glaciers. These are not ordinary rocks."

The ambiguity of chemical evidence leaves geologists hungry for a well-defined, and ideally photogenic, fossil or two. In the early 1990s they thought their hopes had been answered when paleobiologist William Schopf of the University of California at Los Angeles described microscopic structures embedded in a Western Australia formation almost 3.5 billion years old. In his report, dark, slender silhouettes appear in translucent sections of thinly sliced quartz. Schopf says the silhouettes are a complex carbon polymer made by chains of bacteria that may have been anchored to the seafloor. After examining hundreds of present-day microbes, he named 11 possible species in his collection and gave the back story in a 1999 book called *Cradle of Life*. His menagerie made the *Guinness Book of World Records*, as the Earth's oldest fossils.

"I found a whole bunch of different things," says Schopf. "The question was, what were they?"

Schopf decided that at least half could be cyanobacteria, or blue-green algae, the first organisms in the evolutionary record to produce oxygen. That challenges orthodox thinking about conditions on the young Earth, which would not have had a significant oxygen atmosphere for at least another billion years. When geologist Martin Brasier of the University of Oxford had a look at the structures, he decided Schopf was wrong, wrong, and wrong again. The tubes are too branched to come from bacteria, he says. The rock is an extrusion from a hydrothermal vent, not seafloor sediment. And the silhouettes are inorganic carbon injected by the vent and molded into suggestive shapes by the growth of mineral crystals. "Ancient filamentous structures should not be accepted as being of biological origin until all possibilities of their nonbiological origin have been exhausted," Brasier and his coauthors wrote in a report last year.

The hubbub over Schopf's fossils has humbled disciples of early life. "People have become more critical about what they'll accept as evidence of biology," says Knoll. And, as demonstrated by the recent retraction of evidence for life in a Mars meteorite, the stakes are astronomical. Once biologists know where and how life emerged, astrobiologists will be better prepared to look for it elsewhere in the solar system. If life on Earth was a freak accident born of unique and peculiar conditions, it's probably rare elsewhere. But, says Buick, "if life can arise quickly and easily, given the right environment, there might be quite a bit of it out there." ☒

THE PHYSICS OF . . . NEGATIVE PRESSURE

by karen wright

The Minus Touch

The universe doesn't just blow—sometimes it sucks

Red leaves on a piece of celery bear witness to the mysterious force of negative pressure, which, together with capillary action, sends dyed water creeping up the stalk.

PHOTOGRAPH BY MONICA BRADLEY.

THE ROMANTIC POET JOHN KEATS ONCE defined a state of mind wherein a person "is capable of being in uncertainties, mysteries, doubts, without any irritable reaching after fact and reason." He called it negative capability. It stands in direct contrast to the quality known as negative pressure, a scientific conundrum that recently caused much irritable grasping after fact and reason among *Discover* readers.

The trouble started last September, when *Discover* published my Works in Progress column about how water gets to the tops of trees. As water evaporates from a tree's leaves, I reported, it tugs on water remaining in the xylem, a network of inert pipes that reaches from roots to shoots. Water molecules in the xylem, I innocently explained, are linked by bonds that form among their positively and negatively charged poles. As water evaporates up top, it stretches the bonds between interlinked molecules in the column below, generating considerable tension. "The pressure inside the xylem tubes of the tallest trees could be as low as –20 atmospheres," I wrote.

And the irritable grasping began. "Negative pressures of 20 atmospheres? Impossible," one reader wrote. "You can't make empty space more empty!" another protested. "Please tell me that the Works in Progress is a misplaced April Fools' Day article," yet another implored.

For what it's worth, the negative-pressure theory of water transport is enshrined in plant physiology textbooks. But plant physiologists do not have the last word in physics. So I called Princeton University physicist Paul Steinhardt, whom I'd interviewed a year before for an article about the accelerating universe. Steinhardt had gone to great lengths to explain the cosmological version of negative pressure to me. Einstein's equations allow for a ubiquitous, inward-pulling force in the universe that behaves like a rubber band, Steinhardt said. The more you stretch it, the more it pulls back. No one knows exactly what's doing the pulling, but the contracting force could exist in empty space because the vacuum is full of energy and other intangibles.

I asked Steinhardt if the same negative pressure that is tugging on the firmament could also be pulling water to the tops of trees. Not a chance, he said. Liquids can't have negative pressure.

I called plant physiologist Michele Holbrook at Harvard University, a source for the tree story, to give her the bad news. She wasn't buying it. Negative pressure is a legitimate component of fluid dynamics, she told me emphatically, if not irritably. Then she gave me a list of physicists who would vouch for it.

There ensued a messy interlude in which I consulted a sampling of knowledgeable experts, including my brother, Harold. Hal, a high school physics teacher, is wont to say that "the universe doesn't suck; it blows." He means that fluids flow along pressure gradients, from higher to lower pressures. Sucking on a straw, for

Water held in a metastable state has supported tensions as high as –260 atmospheres. Calculations suggest that it can have a tensile strength 50 times higher than that, and other liquids are even stronger. Scientists still don't know how a fluid's properties can confer tensile strength.

example, creates a low-pressure area at the top of the straw, and the higher atmospheric pressure pushes the fluid up from the bottom.

Unfortunately, Hal's law falls short of explaining how water climbs trees. Experiments have shown that atmospheric pressure alone can only push water 33 feet up a vertical tube, and trees can grow much taller than that. Also, I had been told repeatedly that the water in xylem tubes is under tension—which sounded like pulling, not pushing, to me.

Finally, through a contact on Holbrook's list, I found Pablo Debenedetti, an expert in fluid thermodynamics at Princeton whose book, *Metastable Liquids,* includes a section on water transport in trees. In the parlance of fluid dynamics, Debenedetti told me, negative pressure *is* tension—the stress resulting from the elongation of an elastic body. Liquids really can stretch. Under certain conditions, if you pull on them, they pull back. "You can actually have the liquid 'suck' a vessel," Debenedetti said. "In laboratory experiments, you can make vessels implode."

All liquids can have tensile strength, he added, generated by the momentary accumulations of charge from quantum fluctuations in atoms. Tension in liquids has been studied since the mid-1800s. In the 1950s, the National Institute of Standards and Technology determined the tensile strength of a variety of liquids by suspending them in Z-shaped glass tubes with open ends. Each tube was put in a centrifuge and spun around until a bubble formed in the liquid; the liquid's tensile strength was calculated from the centrifugal force required to form the bubble.

Debenedetti confirmed that water's tensile strength is partly a result of attractions between opposite charges on the poles of water molecules. Still, he said, the concept of negative pressures in liquids isn't obvious. At equilibrium, water and other liquids *don't* support tension. It's only a property of metastable liquids—liquids prevented from entering a new phase by an energy barrier. Water can be kept liquid, for example, at temperatures more than 300 degrees Fahrenheit above its boiling point, because it needs a onetime injection of energy to start vaporizing. A liquid under tension wants to be vapor, but it needs a boost, or a lowering of its energy barrier, to change phases. Until that happens—when the liquid is shaken, for instance, or its tension is increased—the liquid stretches. Such is the case in the xylem tubes of trees.

Debenedetti and Steinhardt don't work in the same building at Princeton, but they know of each other because their daughters share the same piano teacher. At my request, the two exchanged a few e-mails and concluded that each man's negative pressure was a stranger to the other. I also approached cosmologist Michael Turner at the University of Chicago, who conferred with his friend Humphrey Maris, a physicist and fluid-dynamics expert at Brown University. After talking to Maris, Turner helped put the two realms together.

"We're not talking about the same phenomena," he said. The two kinds of negative pressure are related, though, "in the sense that they are examples of things that behave elastically. And both are a bit counterintuitive."

If there is a unifying theme here, Turner said, it's direction—an inward, imploding, or contracting force, rather than the outward-pushing force typically defined as pressure. The minus sign next to those atmospheres doesn't mean "less than nothing"; it's an arbitrary signifier denoting "in the direction opposite of positive." Solids have negative pressure when they pull in, like stretched rubber bands or springs. Liquids can have negative pressure in metastable states, when they resist turning to vapor. And, according to the astrophysicists, even empty space can have negative pressure.

Gases are still the dark horse in the meta-stable. Steinhardt has heard that metastable gases can have negative pressure, but he isn't sure how. Debenedetti is skeptical. "The whole point of being a gas is that the forces between molecules don't matter much," he says. Turner is noncommittal.

Since the many facets of negative pressure are obscure enough to escape career physicists, I figure readers can be forgiven their confusion. Negative pressure, it seems, is the perfect remedy for overstretched intellects. ☒

3 WIRES

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2 SPEAKERS

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1 EASY SYSTEM

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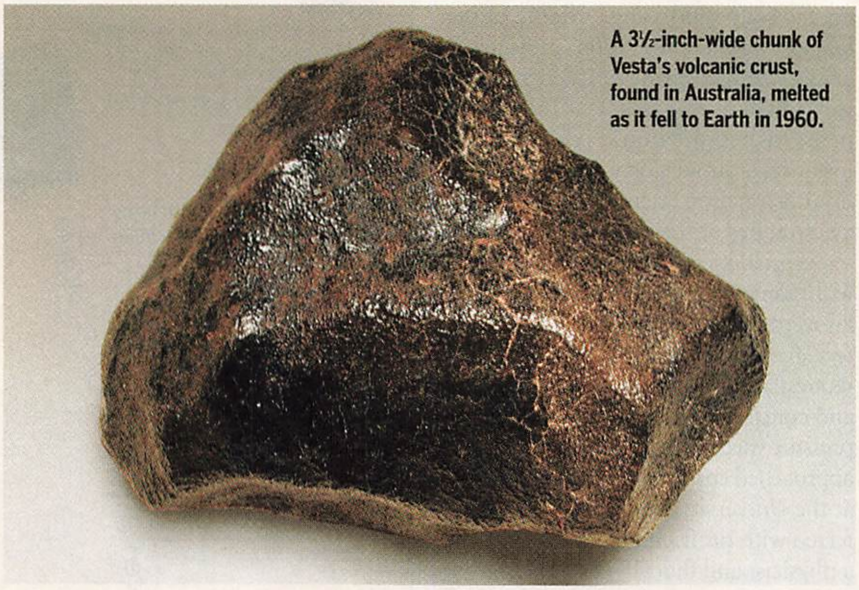
by bob berman



A 3½-inch-wide chunk of Vesta's volcanic crust, found in Australia, melted as it fell to Earth in 1960.

Meet Asteroid Vesta

A chalk white miniature planet of giant craters and frozen lava makes a rare naked-eye appearance

TRY THIS STUMPER ON AN ASTRONOMY-SAVVY friend: What is the smallest celestial body visible to the naked eye? Hint: It lies farther away than the moon, beyond Mars.

The answer is Vesta, an asteroid between Mars and Jupiter. Although it is only 325 miles across, hardly wider than the state of Arizona, Vesta is a world with a complicated geologic history and an intimate relationship with Earth. This month it makes its closest approach in seven years, briefly coming into view as it glides dimly through the constellation Virgo.

The saga of Vesta stretches back to the late 18th century, when scientists speculated that an unseen planet might reside within the wide gap between Mars and Jupiter. On the first day of the 19th century, Italian astronomer Giuseppi Piazzi found a body in the right location and named it Ceres. The situation quickly grew confusing, however, as observers spotted additional small objects in the same region. In 1807 German astronomer Heinrich Olbers discovered Vesta, the fourth of these asteroids (so named because they each resemble a star—*aster* in Latin—through a telescope). It became obvious the missing planet was actually a collection of sub-planetary debris. Researchers have since cataloged more than 40,000 asteroids, some no larger than a house.

Vesta has always stood out from the crowd. First of all, it is peculiarly bright. No other asteroid is visible to the unaided eye, not even Ceres, which is nearly twice as wide. Composition makes the difference. Most asteroids are dark gray, but Vesta is as white as chalk. Once astronomers learned to recognize the milky coloration, they started finding bits of Vesta in surprising places. The mile-wide asteroid Braille, visited by the *Deep Space 1* spacecraft in 1999, appears to be a big chip that broke off Vesta. Smaller pieces of Vesta have even made visits to Earth—and witnesses have watched it happen.

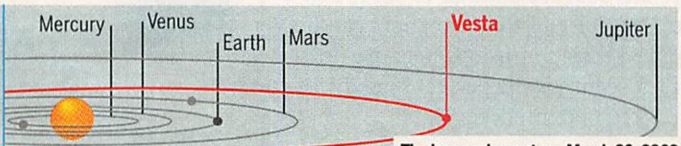
In October 1960, two fence workers in Western Australia witnessed a bright shooting star. Ten years later, when bits of that meteorite were finally found, they proved to be chunks of solidified lava whose colors strongly linked them to Vesta. Only two other bodies, Mars and the moon, are known to have produced fragments that landed on Earth. With pieces of Vesta in hand, scientists could begin to interpret its geology. Apparently it was once a molten world, similar to early Earth, whose interior separated into a mantle and a crust covered with volcanic rock. Planetary researcher Benjamin Zellner of Georgia Southern University calls Vesta "the sixth terrestrial planet."

In September 1997, Zellner published images taken by the Hubble Space Telescope, which provided the first clear look at Vesta. The images showed dark markings—probably plains of ancient lava—and an enormous cavity, 285 miles across and eight miles deep, covering virtually its entire southern hemisphere. Whatever smashed into the asteroid must have hurled tremendous amounts of debris into space. Computer simulations reveal that Jupiter's gravity would have caught some of that material and redirected it into Earth-crossing trajectories.

The huge Keck II telescope joined the Vesta patrol in 1999, producing spectra that showed Vesta's surface is covered with pyroxene and olivine, minerals common in terrestrial volcanoes. These spectra also indicated the ratio of oxygen isotopes in Vesta's rocks. That ratio precisely matches the composition of the Australian meteorites, clinching their identification.

To spot the sixth terrestrial planet for yourself, go out on a clear, dark night and look for the bright orange star Arcturus. Trace a line from there to Virgo's medium-bright star Vindemiatrix, and then extend the line another one-quarter of that span. Sketch the scene and note the very faint star that changes position nightly. That is Vesta.

The tracking process is not easy. At its closest, on March 26, Vesta will still be 119 million miles from Earth, equivalent to a golf ball floating 10 miles away. But when else are you going to see an asteroid? ☒



The inner solar system, March 26, 2003

PHOTOGRAPH COURTESY OF R. KEMPTON/NEW ENGLAND METEORITICAL.

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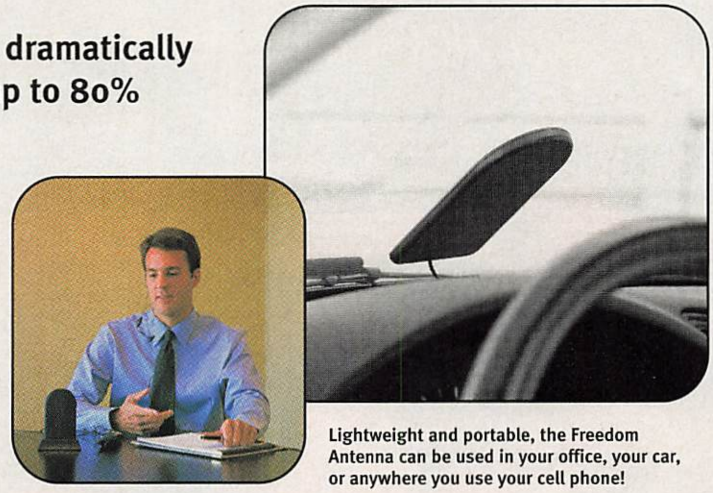

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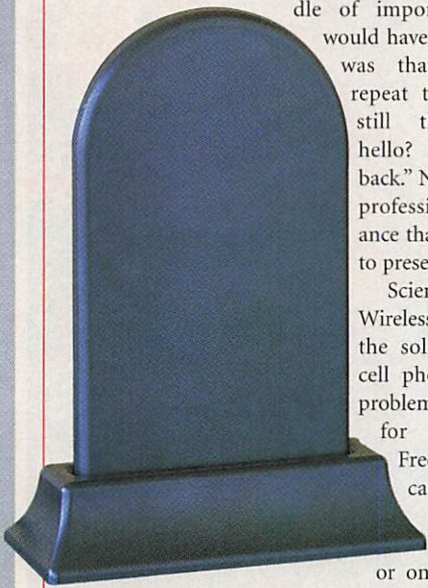

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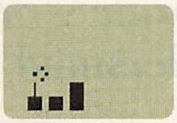

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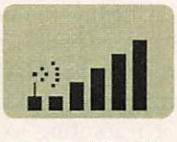

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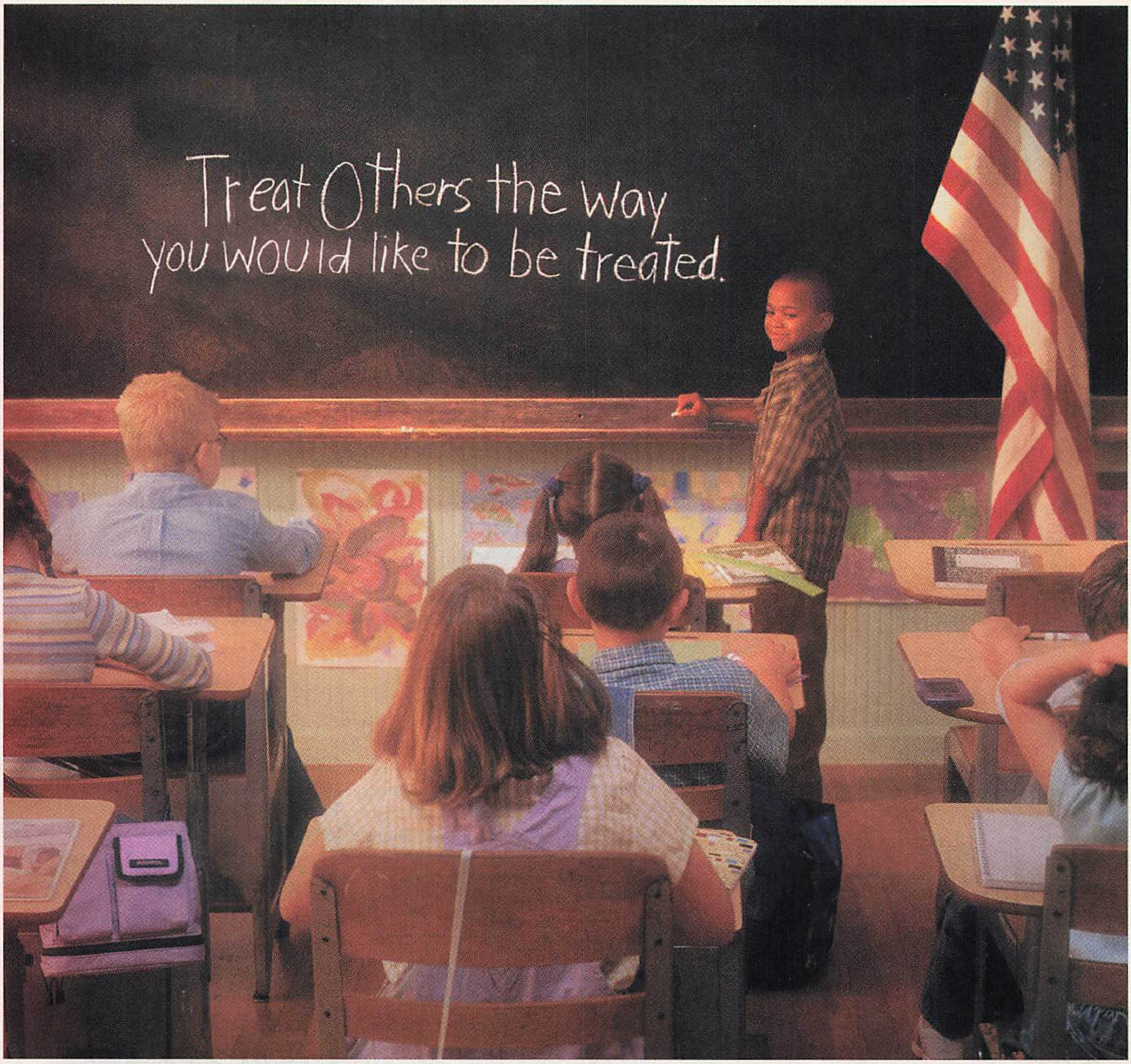
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Negative Emotions

WE HUMANS LIKE TO THINK OF OURSELVES as superior in many ways to animals, but troubling evidence keeps emerging that the line between person and pet is often thin and certainly ambiguous. The surprise isn't just that animals are smarter than we knew or that they too have established cultures, use tools, and can obviously remember events. The reverse scenario, in which humans are a lot more animalistic than we'd like to admit, is just as humbling.

Take this month's cover story, the first in a Learning Series we'll present each month through May on emotions and the brain. Jane Goodall proved years ago that chimpanzees, like us, have emotions. More striking is how primitive some of our human emotions can be. Steven Johnson gets right to the heart of the matter in this month's article on fear. What an old (in terms of evolution), basic part of our brain does when we experience severe trauma like war or an auto accident is downright primitive. It packs our heads full of inerasable memories so we can react—not think—the next time this sort of thing happens to us. But isn't it animals that react and people who think? Think again. There is one universal response to fear seen in both animals and humans: They freeze.

The philosopher Baruch Spinoza was onto this 350 years ago. In a marvelous new book that goes on sale this month—*Looking for Spinoza: Joy, Sorrow, and the Feeling Brain* (Harcourt)—neuroscientist extraordinaire Antonio Damasio explores the Dutch philosopher's amazing insights about emotions (as well as more recent research). Spinoza figured out that the human body does not work very well physiologically in the presence of negative emotions. We now know negative emotions can kill. He also determined that the human body works exceptionally well—Damasio cites a blissful, homeostatic state of contentment like lying on the beach in a lounge chair—when emotions are positive. Spinoza suggested that people try to overcome their negative feelings with positive emotions. The question is: How can the modern mind overcome the evolutionarily old part of the brain? It may seem silly to think that you can think happy thoughts like Peter Pan in the face of painful events like the death of a loved one. But that is exactly what our conscious minds—our last, best hope for being truly different from animals—engage in as evolution plods on.

Sudden loud noises instantly trigger fear, but in a modern age the wolf should be more fearful of us than we are of him.

PHOTOGRAPH BY JOSEPH VAN OS/STONE

LEARNING SERIES

THE BRAIN + EMOTIONS

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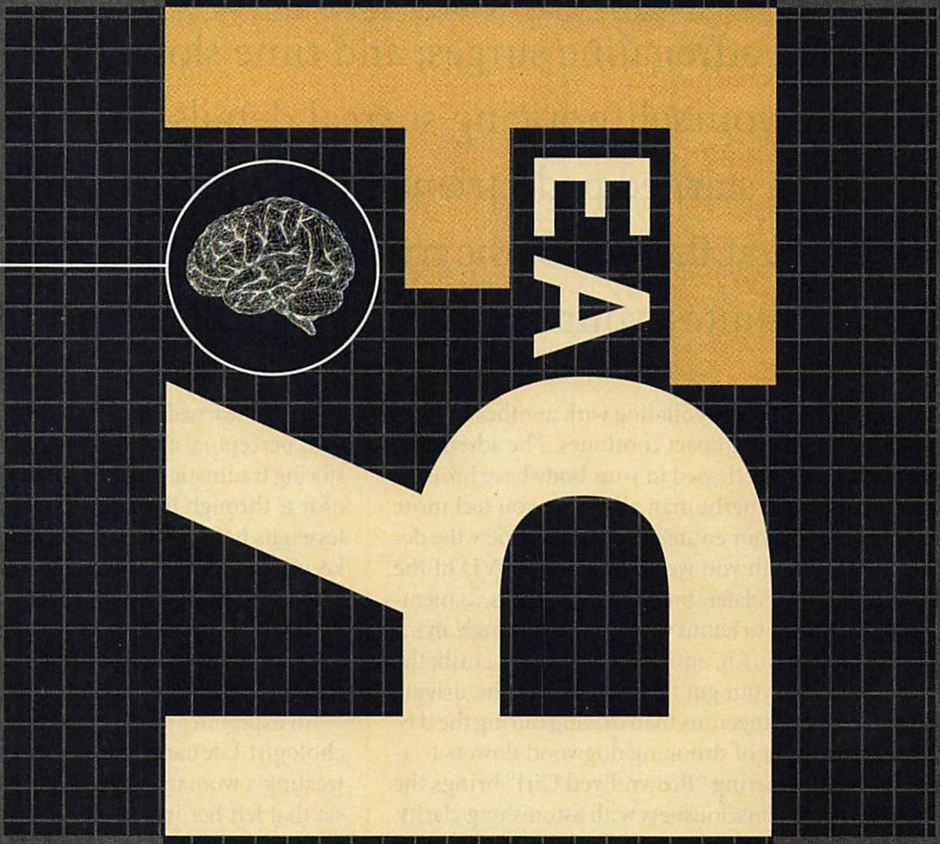
2 LAUGHTER
3 LOVE



RECENT RESEARCH SHOWS THAT WHEN SOMETHING BAD HAPPENS TO YOU, PART OF YOUR BRAIN BEGINS THINKING INDEPENDENTLY, STORING ITS OWN MEMORIES SO IT CAN SAVE YOU NEXT TIME. THAT WORKED FINE A MILLION YEARS AGO

BY STEVEN JOHNSON

PHOTOGRAPH BY ELINOR CARUCCI | GRAPHICS BY DON FOLEY

YOU ARE DRIVING AT NIGHT DOWN A QUIET suburban street, listening to Van Morrison's "Brown Eyed Girl" on the stereo. As you cross an intersection, your peripheral vision picks up the flash of headlights descending on the right side of the car. In the split second before you hear the sound of metal grinding into metal, your body tenses, blood flows to your extremities, adrenaline surges, and time slows down. At impact you find yourself noticing surreal details—the bright orange jacket of a startled pedestrian, the low-hung branches of a dogwood tree at the side of the road. After a split second that seems like 10 minutes, your car lurches to a halt against the curb.

The physical event of one car colliding with another has run its course, but its emotional impact continues. The adrenaline and other stress hormones released in your body have brought you to a state of almost superhuman alertness; you feel more awake than you've felt in your entire life. You can review the details of the crash as though you were replaying a DVD of the event, all the details immaculately preserved. For weeks, as memory fades, details continue to haunt you. Driving through an intersection causes you to flinch, anticipating another crash; the flash of headlights makes your gut tighten. For months, driving at night seems far more dangerous than driving during the day. Even a year later, the sight of drooping dogwood flowers triggers a sense of dread. Hearing "Brown Eyed Girl" brings the whole sequence back to consciousness with astonishing clarity.

Anyone who has been through a traumatic event will recognize this scenario immediately—the sudden physical response of fear and its often debilitating persistence in memory. The feeling of fear, like all emotions, is something that happens to the body and the mind. Few memories are as easily triggered and as hard to shake as those in which we are confronted with an immediate threat. For people who have undergone serious trauma, including war veterans and rape survivors, memories of fear can sometimes play a dominant role in shaping personality, a condition we now call post-traumatic stress disorder.

Unraveling the mystery of how the mind experiences fear—perhaps the most primal and enduring of all the emotions—turns out to be one of the most interesting and instructive quests in the annals of recent neuroscience. We have learned that fear plays tricks with our memory and our perception of reality; we have also learned that the fear systems in the brain have their own perceptual channels and their own dedicated circuitry for storing traumatic memories. As scientists have mapped the path of fear through the brain, they have begun to explore ways to lessen its hold on the psyche, to prevent that car accident from keeping us off the road months later.

It seems intuitive to us that we would remember vividly the details of a frightening event like a car accident. But here is a question with a surprising answer: Would we remember our fear if we had no long-term memory?

An experiment performed nearly 100 years ago by Swiss psychologist Édouard Claparède provides a clue: Claparède was treating a woman suffering from a debilitating form of amnesia that left her incapable of forming new memories. She had suffered localized brain damage that preserved her basic mechanical and reasoning skills, along with most of her older memories. But beyond the duration of a few minutes, the recent past was lost to her—a condition brilliantly captured in the movie *Memento,* in which a man suffering similar memory loss solves a mystery by furiously scrawling new information on the backs of Polaroids before his memories fade to black.

Claparède's patient would have seemed straight out of a slapstick farce had her condition not been so tragic. Each day the doctor would greet her and run through a series of introductions. If he then left for 15 minutes, she would forget who he was. They'd do the introductions all over again. One day, Claparède decided to vary the routine. He introduced himself to the woman as usual, but when he reached to shake her hand for the first time, he concealed a pin in his palm.

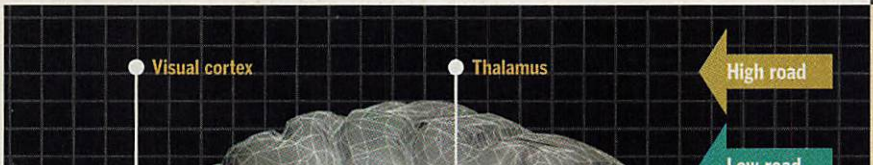
It wasn't friendly, but Claparède was onto something. When he arrived the next day, his patient greeted him with the usual blank welcome—no memory of yesterday's pinprick, no memory of yesterday at all—until Claparède extended his hand. Without being able to explain why, the woman refused to shake. She was incapable of forming new memories, yet she had nevertheless remembered something—a subconscious sense of danger, a remembrance of past trauma. She failed utterly to recognize the face and the voice she'd encountered every day for months. But somehow, buried in her mind, she remembered a threat.

ABOUT 25 YEARS AGO, A YOUNG POSTDOCTORAL STUDENT AT WEILL Medical College of Cornell University in Manhattan named Joseph LeDoux was casting about for a research focus. Cognitive science, with an emphasis on computer modeling, was the hot new field. But LeDoux was interested in emotions, and "there wasn't a lot going on there," he remembers, sitting in his office at New York University, where he is a professor of neural science. "So I read around and came across studies on fear conditioning." Claparède's pin turns out to be a somewhat diabolical twist on the classic behaviorist experiment of fear conditioning: Put a rat in a cage, play a tone, and simultaneously deliver a shock to the animal. After a few rounds of tone and shock, the rat starts to fear the tone even if it's not accompanied by the shock. The fear reaction—noticeable because the rat freezes in place—has been observed in species as diverse as pigeons, rabbits, baboons, and humans. It is called a conditioned response. The rat has an unconditioned innate fear of shocks, but it can be conditioned to be afraid of tones if the two are associated with each other. In Claparède's version of the experiment, the pin was the shock. His outstretched hand was the tone. After only one exposure to the shock and the tone, the amnesiac patient acquired a conditioned fear response to shaking hands with her doctor.

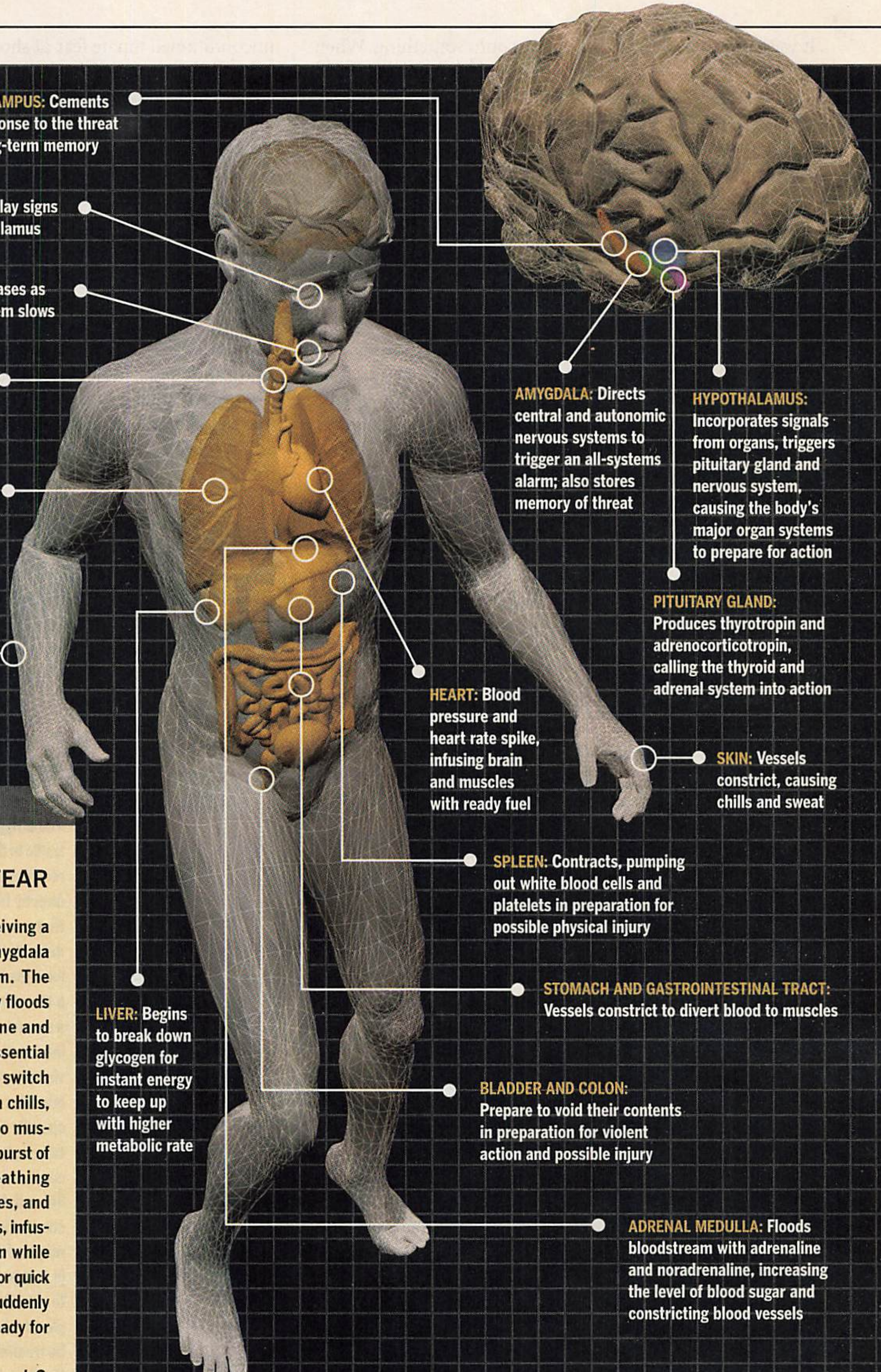
Conditioned fear is easy: Fruit flies, marine snails, even lizards can be trained to display defensive behavior in response to threatening stimuli, along the lines of the tone and shock experiments. Conditioned fear turns out to be one of the most essential techniques that natural selection stumbled across to increase the survival odds of organisms in an unpredictable environment. But until a few decades ago, we had almost no idea how that learning actually took place. The ubiquity of conditioned fear in the animal kingdom, combined with the amnesiac's ability to remember potential threats, made it clear that learning to be afraid involved different mechanisms than, say, learning how to ride a bicycle or memorizing the capitals of all 50 states. But what was the mechanism? That's what LeDoux set out to determine. There had been almost no research into how the fear response actually came into being. "In fact," LeDoux says with a smile, "my first grant on this topic in the early 1980s was turned down," because scientists reviewing his application believed it was impossible to scientifically study emotions.

LeDoux forged ahead anyway. "I started from the outside," he says. "I had the sound that produced the fear response. I wanted to know: How does that sound go through the brain

BRAIN BYPASS



The amygdala, which directs signal traffic in the brain when danger lurks, receives quick and dirty information directly from the thalamus in a route that neuroscientist Joseph LeDoux dubs the low road. This shortcut allows the brain to start responding to a threat within a few thousandths of a second. The amygdala also receives information via a high road from the visual cortex. Although the high road encodes much more detailed and specific information, the extra step takes at least twice as long—and could mean the difference between life and death. LeDoux says the disconnection between the two routes may underlie some disorders: "While in terms of survival it may be better to mistake a stick for a snake, people who have pathological fears may be treating sticks as snakes much of the time." ***—Jocelyn Selim***



HIPPOCAMPUS: Cements the response to the threat into long-term memory

PUPILS: Dilate, ready to relay signs of danger to the visual thalamus

SALIVA: Decreases as digestive system slows

THYROID GLAND: Raises resting metabolic rate

LUNG: Bronchioles dilate, taking in more oxygen

HAIR: Stands on end

AMYGDALA: Directs central and autonomic nervous systems to trigger an all-systems alarm; also stores memory of threat

HYPOTHALAMUS: Incorporates signals from organs, triggers pituitary gland and nervous system, causing the body's major organ systems to prepare for action

PITUITARY GLAND: Produces thyrotropin and adrenocorticotropin, calling the thyroid and adrenal system into action

HEART: Blood pressure and heart rate spike, infusing brain and muscles with ready fuel

SKIN: Vessels constrict, causing chills and sweat

SPLEEN: Contracts, pumping out white blood cells and platelets in preparation for possible physical injury

STOMACH AND GASTROINTESTINAL TRACT: Vessels constrict to divert blood to muscles

LIVER: Begins to break down glycogen for instant energy to keep up with higher metabolic rate

BLADDER AND COLON: Prepare to void their contents in preparation for violent action and possible injury

ADRENAL MEDULLA: Floods bloodstream with adrenaline and noradrenaline, increasing the level of blood sugar and constricting blood vessels

ANATOMY OF FEAR

Within seconds of perceiving a threat, the primitive amygdala sounds a general alarm. The adrenal system promptly floods the body with adrenaline and stress hormones. Nonessential physiological processes switch off. Digestion stops, skin chills, and blood is diverted into muscles in preparation for a burst of emergency action. Breathing quickens, the heart races, and blood pressure skyrockets, infusing the body with oxygen while the liver releases glucose for quick fuel. The entire body is suddenly in a state of high alert, ready for fight or flight.

—J. S.

and create the response?" Like most brain researchers in the age before advanced imaging technology, LeDoux's approach was surgical subtraction. Take a healthy rat and begin extracting specific parts of his brain. If you remove a region and the rat can still learn to associate the tone with the shock, then the region you've removed isn't relevant to fear conditioning. But if the rat stops learning, you know you've got something relevant.

"Because the auditory pathways are fairly well worked out in mammals, I could use that as a starting point. I started with the top of the auditory pathway, which is the auditory cortex. I took that out, and the animals learned fine. Then I went down one station to the auditory thalamus, took that out, and they couldn't learn at all. So that meant that the sound had to go through the system to the level of the thalamus but didn't go through the cortex. So where was it going?" The question was puzzling because the traditional understanding of the brain's activity emphasized the role of the cortex over most other regions. The cortex was where the sensory information—in this case, the sound of the tone—was integrated into conscious awareness, alongside other sensory data transmitted from other parts of the brain. The auditory thalamus was supposed to be just a relay station from the ear to the primary destination, the auditory cortex. So there was something strangely inverted about LeDoux's result. You could eliminate the primary destination altogether without affecting the learning, but if you took out the relay station, the learning stopped.

Your body knows how to execute the freezing response without any training at all

LeDoux's assumption was that the auditory thalamus harbored a link to another part of the brain, in addition to its link to the cortex. Using a tracer dye to follow pathways out from the auditory thalamus, LeDoux discovered a connection to the amygdala, an almond-shaped region in the forebrain long associated with emotional states. When he removed the amygdala, the rats failed to learn. Perusing the literature, he found earlier experiments that demonstrated a crucial part of the amygdala known as the central nucleus contained links to the key brain stem areas that control the autonomic functions involved in the fear response, like acceleration of breathing and heart rate. "I didn't start out looking for the amygdala," LeDoux says. "The research led me to it."

The key insight that emerged is that the experience of danger follows two pathways in the brain: one conscious and rational, the other unconscious and innate. These were quickly dubbed the high road and the low road. Say you're walking though a forest, and out of the corner of your eye you detect a slithering shape to your left, accompanied by a rattling sound. Before you even have time to formulate the word *snake,* your body has frozen in its tracks; your heart rate has accelerated; the sweat glands on your palms have dilated. In your brain, the information flow looks something like this: Your eyes and ears transmit basic sensory information to the auditory and visual thalamus, where the information is then transmitted along two paths. One stream of data heads towards the cortex, where it will be integrated with other real-time sensory data, along with more elaborate associations like the word *rattlesnake,* or your childhood memories of a pet python, or the snake scene from *Raiders of the Lost Ark.* At the same time, the slithering is also transmitted—in less rich detail—to the amygdala itself, which blasts out an alarm to the brain stem, alerting the body that a potential threat is nearby. The key difference between the two paths is data transmission time. It might take a few seconds to establish the presence of the snake and formulate a response via the high road, but the low road kicks the body into a freezing response within a fraction of a second. And you don't have to learn the elaborate bodily choreography involved, the way you might learn a complicated yoga position. Your body knows how to execute the freezing response without any training at all. In fact, it knows the response so well that it is nearly impossible to keep it from happening.

As a survival mechanism, LeDoux's low road made perfect sense. But other questions remained: How did the amygdala know to be afraid of a snake in the first place? How could Claparède's patient learn to be afraid if she lacked memory?

We're accustomed to describing someone as having a good or a bad memory, as though memory were a single attribute that covers the entire range of storing and recalling information. We now know that the brain's memory systems are far more diverse than this. There are systems devoted to explicit or declarative memories, like your childhood recollection of that pet python, and systems devoted to procedural memories that usually involve physical movement, like learning how to ride a bicycle. And then there are emotional memories. If you watch the activity in someone's brain using a modern fMRI scanner, you see a different profile depending on which kind of memory the subject is conjuring up.

In ordinary cases of fear conditioning—encountering that snake in the grass—a declarative memory will occur more or less simultaneously with an emotional memory. You'll feel the freezing response kick in, and moments later you'll remember seeing that scene from *Raiders of the Lost Ark.* The latter feels like our traditional idea of memory; there's a mental picture from the past experience that comes into consciousness, as though you were sifting through pages of a photo album. The transition to a freezing response doesn't feel like a memory in that conventional sense of the term, but for all intents and purposes it is one. It is recalled information from past experience

The brain seems to be wired to prevent the

that alters your state of mind. The transition to a freezing response happens too fast for it to be a conscious, deliberate memory, but it's a form of memory nonetheless.

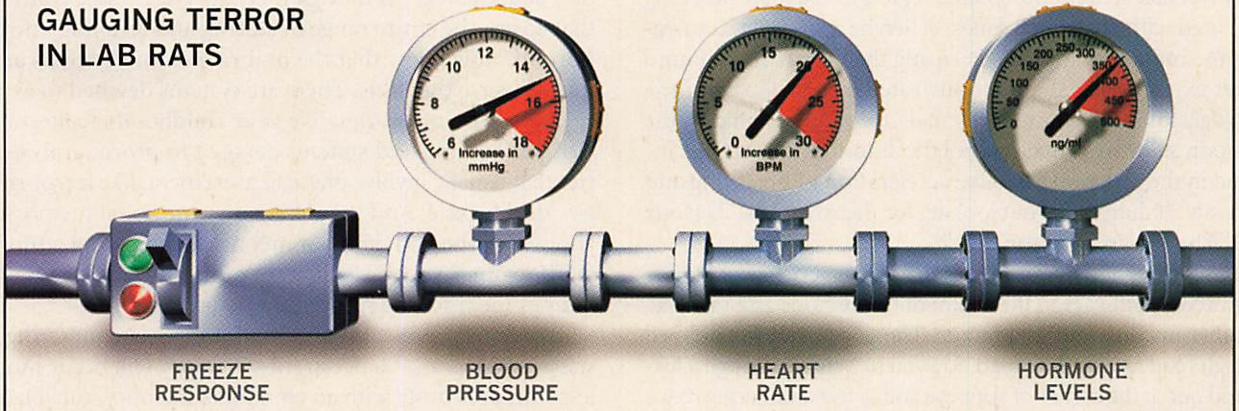
In brain anatomy terms, the declarative memory of Indiana Jones in the snake pit is laid down by the hippocampus, a long, curved ridge located next to the amygdala. The emotional memory of a threat, on the other hand, is mediated by the amygdala itself. This explains the mystery of the remembered pinprick: Claparède's patient lacked the ability to form declarative memories, but she had a functioning amygdala that kept the memory alive, albeit unconsciously. If you had a past encounter with a snake and you felt actively threatened, a trace of that memory would have been stored by the amygdala as well as by the hippocampus. Some brain scientists believe that our fear systems are prepared to learn about threats—snakes, spiders, or heights—that have been major obstacles to survival over the millions of years it has taken the modern brain to evolve, which explains why it is easier to develop phobias about snakes than about threats that are statistically much more likely to kill you, such as electricity.

Some scientists believe the amygdala doesn't have its own discrete storage system for emotionally charged memories but rather marks memories created by other brain systems as being somehow emotionally significant. In 2001 James McGaugh of the University of California at Irvine conducted a telling variation on the classic fear-conditioning experiment. He took a rat and subjected it to the traditional foot shock if the animal took a step. After administering the shock, McGaugh injected cyclic AMP—a cellular messenger that strengthens neuronal synapses, leading to stronger memory—into the animal's cortex. Two days later, the rats were tested to see how well they were conditioned; those that received the injections turned out to have enhanced memories of the shock. "So we know the cortex is involved in the memory that's based on fear in that situation," McGaugh says. "Now, if we make a lesion of the amygdala, the stimulation of the cortex doesn't do anything. In other words, you have to have a working amygdala for the cortex to do its job."

McGaugh concludes, "That experiment tells me that fear is not learned *in* the amygdala. Amygdala projections are coming up to brain regions where information is being stored, and they're saying: 'You know this memory you're storing? Well, it turns out to be a very important one, so make it a little stronger, please.' It provides selectivity in our lives. You don't need to know where you parked the car three weeks ago, unless it was broken into that day." You can think of it as the brain's way of underlining.

THE TROUBLE WITH EMOTIONAL MEMORIES IS THAT THEY CAN BE fiendishly difficult to eradicate. The brain seems to be wired to prevent the deliberate overriding of fear responses. Although there are extensive neural pathways from the amygdala to the

GAUGING TERROR IN LAB RATS



Neuroscientists have determined that the memory of a fear stimulus triggers dramatic changes in the vital signs of rats. In a series of conditioned-response experiments, rats are first exposed to a painful shock accompanied by a tone. Whenever the tone is repeated, the rats immediately stop dead in their tracks. Blood pressure shoots up within three seconds, and heart rate peaks within five seconds. After 20 seconds, increased levels of stress hormones like corticosterone flood the body, and highly oxygenated and fuel-charged blood is pumped into the muscles to prime them for action.

deliberate overriding of fear responses

neocortex, the paths running the reverse direction are sparse. Our brains seem to have been designed to allow the fear system to take control in threatening situations and *prevent* our conscious awareness from reigning.

This may have been an optimal design for predator-rich environments in which survival was a minute-by-minute question, but it is not a good adaptation for modern environments in which the stressors can be job performance reviews. The amygdala may be looking out for your best interests by preserving a memory of that nighttime car accident, but if the result is an inability to drive after dark, the fear circuitry has gone too far. Because the low-road memories are so tenacious, one question neuroscience is now wrestling with is how to subdue the amygdala when those memories hurt the organism.

As a New Yorker who works in downtown Manhattan, LeDoux has been thinking a lot about these issues since September 11, 2001. Many local residents experienced a conditioned fear response that day, making it hard for them to work in tall buildings or visit the downtown area. LeDoux suspects those traumatic memories will persist in the brains of New Yorkers. The treatment possibilities are not about eliminating the memories so much as retraining the amygdala to respond differently when those memories are triggered.

"The contrast," LeDoux says, sitting in his university office above Washington Square Park, with Ground Zero lurking not far to the south, "is between taking action and being stuck, frozen in fear, headed toward despondency, unable to control your life. There's an interesting experiment along these lines: You have a rat that goes into a chamber. A tone goes off, and he gets a shock, and he freezes with the fear response. The next day he goes into chamber B, the tone goes off, and he freezes. But if he takes a step, the tone stops. Eventually he learns that he has to crawl across the chamber to eliminate the tone completely. So by taking that action, he's able to prevent fear from existing in his life.

"In order for the rat to do this," LeDoux continues, standing up to sketch out his ideas on a cluttered white board, "he's got to throw a switch in the amygdala. Normally, the fear response goes from the lateral nucleus to the central nucleus and then out of the amygdala. In order for the rat to take a step, the stimulus has to go not to the central nucleus but to the basal nucleus, and then out to the parts of the brain that are involved in active behavior." In other words, the amygdala wants to associate the memory with the freezing response, but it can be trained to associate it with something less debilitating. When you hear an airplane rumbling overhead, you can freeze, or you can take a step. And with every step you reroute the path of fear through the amygdala.

Our new understanding of fear has also led to cunning pharmacological treatments for post-traumatic stress disorder. McGaugh talks about two recent studies that involved giving beta-blockers to people who had recently suffered a traumatic event, studies that built on McGaugh's own research: "Say you have a traumatic experience. The memory of that experience will pop into your brain the next day, whether you want it to or not. And when that memory pops into your brain, you're going to have that whole autonomic response that you had originally. It's going to come back again. So it's not only that you remember that you were mugged, but you also get very emotionally excited about it when the memory happens." That emotional excitement triggers the memory-enhancing cycle all over again, making the traumatic memory even stronger, like a spinning tire deepening the muck hole it's stuck in with each jab on the accelerator. By preventing the autonomic reaction, beta-blockers keep the memory from forming deeper grooves in the brain, making post-traumatic stress symptoms less severe, "which I think is a really interesting development," McGaugh says with a hearty laugh. "Forty-five years of my life I've spent studying rats and out pops something useful!"

BECAUSE THE FEAR RESPONSE CAN PLAY A DIRECT ROLE IN LIFE-AND-DEATH struggles, it's not surprising to find that the brain contains elaborate machinery dedicated to its routines. The fact that the amygdala's basic architecture reappears in so many species is testimony to its evolutionary importance: Natural selection generally doesn't tinker with components that have proved essential to basic survival. Of course, the persistence of the low road in a world where predators are largely nonexistent may no longer be adaptive, but that's the trade-off of human culture. Evolution made our brains so smart that we ended up building environments that made some of our mental resources obsolete. No matter how calculating and erudite the neocortex becomes, it can't simply switch off the amygdala. In that sense, you can see the battles between these different regions as a re-enactment of Freud's clash between man's civilized superego and his primal id.

There is great elegance in the way this system has evolved, with its complex mix of instinct and learning. Like all emotions, the fear circuitry steers the organism toward desirable states—away from predators or other threats—without knowing that much in advance about the world that the organism will actually inhabit. We are not slaves to our emotions, but they are hardly at our beck and call either. They propel us in directions that our rational minds don't always understand—fear most of all. The amygdala, like the heart in Pascal's famous phrase, has reasons of which reason knows nothing. ☒

"I am a very old-fashioned anthropologist," says Sarah Blaffer Hrdy. "I believe that my mission is to understand human nature in all of its variations."

The hardy Sarah Blaffer Hrdy

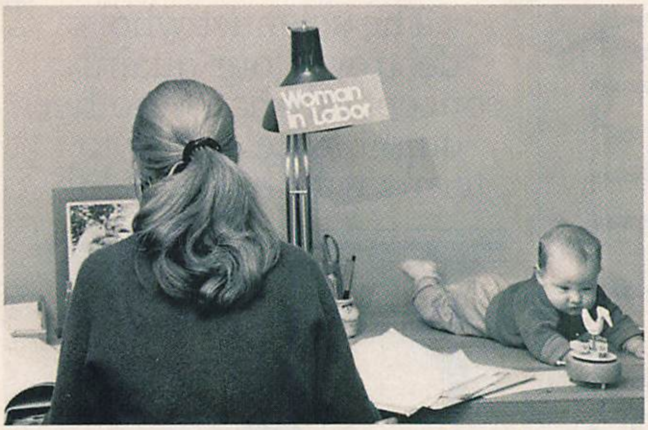
The scientist who destroyed our quaint concept of what a mother ought to be comes to terms with her own life

THE BITCH IS a Rhodesian Ridgeback named Nyoka, Swahili for "snake." She is a handsome chocolate animal big enough to hunt down a wildebeest. Her owner bred her, and she whelped 16 pups. Several died at birth. There was one runt, a tiny, perfectly formed female. No matter how many times Nyoka's owner put the runt to the teat, when she came back later she found the pup pushed away, as if an imaginary circle surrounded the mother and her marginal offspring had not been permitted inside. "Ah," thought the owner, anthropologist Sarah Blaffer Hrdy, "yet another example of maternal instinct."

Motherhood has been of consuming interest to Hrdy (rhymes with birdie) for years now. Her theories about why mothers—as well as fathers—behave as they do brought her scorn, and then respect, as one of the most radical evolutionary thinkers of our day. In her most recent book, *Mother Nature: Maternal Instincts and How They Shape the Human Species,* she demonstrated that mothers may abort, abandon, or even kill offspring they do not have the resources to rear. Her assertion that infanticide is common to species across the animal kingdom shook biology, especially when

BY CLAUDIA GLENN DOWLING

PHOTOGRAPHY BY
JENNY GAGE & TOM BETTERTON



As a postdoctoral researcher at Harvard—and the mother of a daughter—Hrdy was working two jobs. "She was very caring," says Katrinka (at right), now 25 and a teacher. "But as I got older, I realized the conflict she felt."

"Single-minded devotion is typical of ape mothers," says Hrdy, but that doesn't keep a langur female from accepting child care from another tribe member (right). "Mothers elicited assistance where they could get it."

she applied her theories to *Homo sapiens.* Her feminist reinterpretation of evolutionary theory, as well as data, challenges the archetype of "the good mother," a natural Madonna, and replaces her with a more complex female figure—ambitious, calculating, nurturing, selfish, loving, sexually assertive. The Ridgeback's behavior, which saddened Hrdy, "was a kind of confirmation," she says.

Six feet tall and rangy, with a big Texas smile, Hrdy, 56, doesn't look like a radical who wants to upset the mom-and-apple-pie order of our cultural norms and public policies. Yet her contention, backed up by research, that motherhood is a burden seldom embraced unconditionally has profound implications. Her message is clear: Many women with no access to support systems will choose abortion over a marginal existence and penury.

Hrdy maintains that a human infant is so costly to raise—requiring 13 million calories to attain adulthood—that mothers since the Pleistocene Epoch have made calculated decisions about when, how, and whether to rear them.

That rare scientist who is willing to use her own life as an object of research, she openly discusses how ambivalent she was 25 years ago when "I found myself torn between my work and an admittedly adorable but insatiably demanding human baby." She points out that today—when for the first time in the history of the human species, females have a choice about conceiving children—birthrates are plummeting not just in Europe and the United States but also in less developed nations like India and Brazil. "Women are voting with their ovaries," she says, "opting to delay births, to have only one or two children, or none at all."

Hrdy believes that if a male scientist made such claims, his peers would be unlikely to question his relationship to his research. Yet she knows from experience that, as a female writing about females, her life comes under the lab lights. Colleagues have at times been so threatened by her ideas that their attacks have gotten personal. An evolutionary biologist once commented, "Sarah ought to devote more time and study and thought to raising a healthy daughter." That remark stung—he had hit on Hrdy's secret guilt.

Still, over the years Hrdy has had the satisfaction of not only watching her three children grow up happily but also seeing her radical ideas become mainstream and her colleagues come around. So, these days, she makes a pre-emptive strike: Her quest, she says, is "to understand not just who I am, but how creatures like me came to be." For her, everything—whether experienced, observed, or consumed in the literature she tears through—is a piece in a giant jigsaw puzzle she's trying to fit together, a picture of how the human family is evolving. Her brain, like a kaleidoscope, realigns patterns, illuminating them with a clear, startling light.

HRDY'S FIRST BOOK ABOUT INFANTICIDE AMONG PRIMATES, *The Langurs of Abu: Female and Male Strategies of Reproduction,* was published in 1977. At the time, biologists questioned her research and sniped. "Sarah Hrdy's monkeys are deranged," she recalls one prominent physical anthropologist saying. She had witnessed male langurs attacking infants sired by rivals and leaving them for dead to clear the way for impregnating females with their own genes. But she also observed that females employed their own strategy to counter such behavior. When an alpha male took over the tribe, the females would simulate estrus, the period of ovulation, to copulate with him and convince him that he was the father of their offspring, thereby gaining his protection. Hrdy's conclusions are widely accepted today. "You have to really put your head in the sand now to dispute the matter," says Alison Jolly, author of *Lucy's Legacy: Sex and Intelligence in Human Evolution* and former president of the International Primatological Society.

Hrdy's next book, *The Woman That Never Evolved,* "hit a lot of nerves too," Jolly adds. In that study, published in 1981, Hrdy suggested that primate females evolved many strategies, including forming alliances with other females, to counter male dominance. She argued that Charles Darwin's notion of a passive or coy female role in sexual selection stemmed from comparatively recent social conventions and didn't apply to most primates, including some human societies. Again the knives came out. "'So, Sarah, put it another way—you're horny, right?'" Hrdy remembers one colleague quipping. "That was

PHOTOGRAPHS: LEFT, GEORGIA LITWACK; RIGHT, COURTESY OF SARAH BLAFFER HRDY.

the most mortifying moment of my life," she says. Now her insights are accepted. Says the once-dismissive Robert Trivers, an evolutionary biologist and professor at Rutgers University who advised Hrdy at Harvard University, "Her argument that by copulating with numerous males, the female gives the others the illusion of paternity, which tends to make them more solicitous of offspring—that theory's worn well."

In *Mother Nature,* published in 1999, Hrdy synthesized her previous work, positing that both infanticide and polyandry—the tendency for females to mate with more than one male—exist because humans evolved as cooperative breeders and, as such, are ill-equipped to cope without helpers. Historically, humans have made use of allomothers, she maintains. *Allo* means "other than" in Greek, so allomothers are group members who help a mother rear her child. They may be female (older sisters, aunts, grandmothers) or male (brothers, lovers, and fathers). The absence of support networks for modern mothers may explain why so many newborns are dumped in bathrooms, Hrdy says.

"She's done it again," Jolly says. "To say that a child may be abandoned because a mother has to save her own health first—this is not saying abandoning children is good or abortion is good. Sarah's saying that, to prevent mothers from making this decision, they need help raising their children. I hope *Mother Nature* causes political pressure for the provision of child care. Human mothers need help."

Hrdy herself was brooding about whether she would need help to raise her children on the day she first met Jolly 26 years ago. The mother of four, Jolly has served as a role model for many young female scientists over the years. At the time, she was lecturing at Harvard. One of a crush surrounding the visitor, Hrdy blurted, "But what is your life like?" She meant "How do you juggle your responsibilities?" At the time, she wasn't at all sure she herself would be able to do it.

SARAH BLAFFER GREW UP DETERMINED TO BE A BETTER MOTHER THAN her own mother had been. She had been raised in the 1950s, before the psychologist John Bowlby showed that primate babies need to attach securely to a mother figure. The prevailing wisdom was, "If a child cries, don't pick it up," she recalls. Her mother was a woman of the times, distant with her infants. "My mother was, by some standards, an appalling mother," Hrdy says. "But I loved her tremendously."

The daughter was determined to use her brain, at least in part to make up for her mother's thwarted intellectual ambitions. After graduating from Wellesley College, Sarah's mother had wanted to go on to law school, but her family insisted that she come home to Dallas to make her debut instead. "All that was open to her was to marry advantageously," says Hrdy, which she did. Sarah's father, heir to an oil fortune, sired four daughters before he got the son he wanted. Sarah was the third. "I was a bluestocking from the word go, and in the social environment in which I grew up, that was not acceptable," she says. "But I was the heiress to spare, and that left me a lot of freedom." An intellectually stimulating boarding school allowed her, at 16, to dream of a life of the mind. She went off to her mother's alma mater, then transferred to Radcliffe and eventually made her own token curtsy to society. After graduating summa cum laude and Phi Beta Kappa in 1969, Sarah went on to earn a doctorate in anthropology at Harvard. Her mother took vicarious delight in Sarah's successes, and in adulthood the two grew so close

> 'My mother was, by some standards, an appalling mother, but I loved her tremendously'

In the forest, a pregnant adult langur, grown tired of baby-sitting, lets an infant slide between her legs (center). A juvenile female (right) eagerly waits to take over—"important practice caring for infants," says Hrdy.

Katrinka accompanied her mother on two trips to India, but she remembers little more than the scents. After the second journey, Hrdy decided that the demands of fieldwork and motherhood were incompatible.

PHOTOGRAPHS COURTESY OF SARAH BLAFFER HRDY.

that for a year after her mother's death in 1991, Sarah reached for the phone every morning to ring her as usual.

In graduate school she realized how difficult it was for a female to break into the boys' club of science. "I was blown away," she recalls. "All my life I had felt guilty for being overprivileged, and all of a sudden people were discriminating against *me*." Once, filling in for a missing lecturer, she was introduced as "the woman who has just written a book about a six-meter-long, death-dealing penis," a reference to *The Black-man of Zinacantan,* her book about a Mayan legend. "I was irritated and am sure I gave a better lecture as a result." Hrdy concludes, "I learned that you could get so mad that you would want to become a revolutionary."

Female scientists are different from males, Hrdy says, only in that because they empathize with female subjects, they ask different questions: "The science is the same." She recalls once discussing female libido with several scientists. A man suggested doing a study to determine whether sexual desire was cyclical in human females, as it is in other primates. The women looked at each other and said, "We don't have to." They assumed that libido was higher at the time of ovulation and were more interested in asking why than whether. Hrdy now believes that some of her contrarian insights, such as that killing infants might be adaptive behavior, may have grown out of her struggle against male bias in anthropology and evolutionary biology. "It was painful at the time, but I think it was probably very fruitful," she says. "I started to challenge conventional wisdom, which is a good thing to do."

'I learned that you could get so mad that you would want to become a revolutionary'

For a revolutionary, her private life has been traditional. This woman who contends that females are often polyandrous has herself been a constant mate since 1970, when she fell in love with Daniel Hrdy in Anthropology 101, a Harvard class taught by the grand old man of physical anthropology, William Howell. Two years later, as Daniel headed off to the Solomon Islands to collect hair samples and Sarah left for India to study langurs, they married in Kathmandu. The two Dr. Hrdys—he genial and tidy, she wired and messy—have been together ever since. When Sarah Blaffer Hrdy collected the W. W. Howell Prize for an outstanding contribution in biological anthropology in 2001, she said in her speech, "the real prize was Dan."

For nine years, the couple commuted between Boston and India as Sarah studied primate behavior and Daniel, a specialist in infectious diseases, studied rotaviruses. "It was the happiest time of my life—being outdoors with animals who were beautiful and fascinating, solving a puzzle, leaving problems and everyday life behind." Then motherhood changed everything. At 31, she had her first and "very wanted" daughter. "Overwhelmed by the child's lusciousness," the new mother made up a lullaby: "Katrinka, Katrinka, lovely little Katrinka, with velvety skin and silky hair, everybody's so glad that you are there." What she terms "the honeymoon period" gave way to frustration because she couldn't find time to write or do research. On one of her last trips to India, she took along a paid allomother (what Mama would have called a nanny). Katrinka developed "virulent diaper rash—she was one unhappy child." One evening Hrdy came home to find that the toddler was being attacked by a troop of monkeys trying to snatch her cookie. The overextended biological mother suffered agonies of guilt. On the flight home, sick with pneumonia and a fever of 104 degrees, Hrdy lay across the middle row of seats drinking water from a baby bottle. The day they got home, the baby-sitter quit. "Fieldwork is incompatible with having children," Hrdy concluded. If she wanted her children to have a greater sense of security than she did growing up, she had to give up her field research. "You compromise to have a family, but you don't give everything up," she says now.

With more children came more compromises. In 1982 an international symposium on infanticide in animals and man was scheduled at Cornell University after the due date for the birth of her second child. However, a strict no-babies rule was imposed by a male co-organizer. Daughter Sasha arrived just a week before the meeting, and her mother's plans to establish breast-feeding were thrown into disarray. Hrdy nursed in the evenings, while a friend who was also nursing fed Sasha her breast milk during the day so Hrdy could present her paper. It worked. Son Niko was born in 1986, when Hrdy was 41. "That was the year I won a Guggenheim fellowship to write a book on the natural history of motherhood," she recalls, "which somehow did not get written that year." It did not become a book—the 700-page *Mother Nature*—for another 13 years.

Those experiences have made Hrdy a fierce advocate for good day-care programs, which she considers the modern substitute for a tribal network of allomothers. She visits centers around the world to study their techniques and lobbies government child-care agencies for higher standards. "Stability, stability, stability," she reiterates. She finds it inconceivable that anyone doubts that quality day-care programs are worthy of public funding. She says the woman who drowned her five children in the bathtub in Texas is a tragic example of the need for a support system. "She should not have been alone in that house with five young kids and a record of depression—it's a no-brainer. Not even a mentally healthy woman should have to be in that situation."

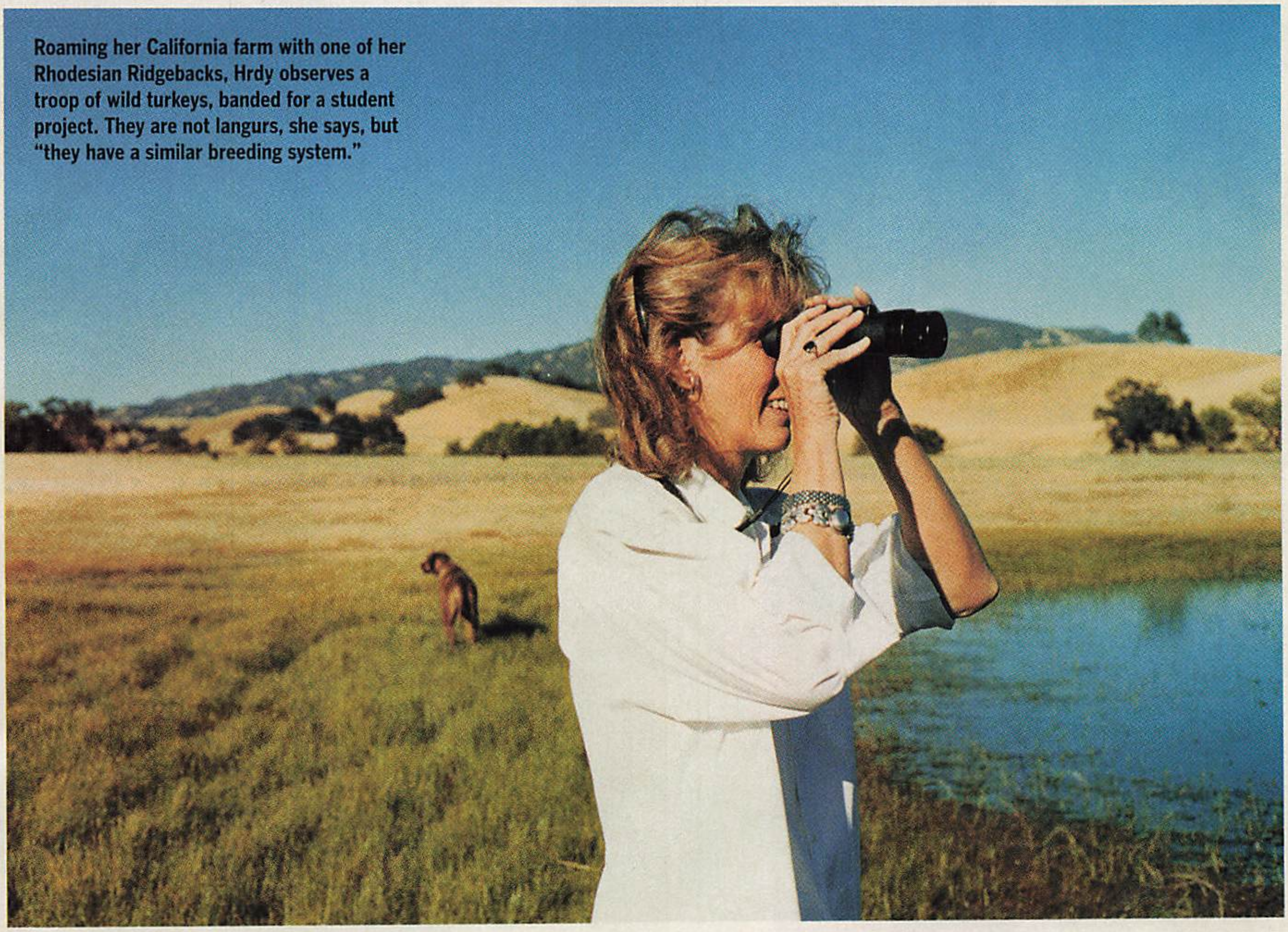
Hrdy realizes her privileged circumstances are far different from those of most mothers. Katrinka had a series of au pairs, and both younger children had long-term caregivers. All went to boarding schools in New England, and both daughters went on to Harvard. Hrdy feels irritated by the accusation that her theory of cooperative breeding is a rationalization of her own choices, but she acknowledges being the rare female of her generation who has integrated maternal and scientific voyages of discovery. Trivers, who once doubted her ability to do it all, says, "Sarah's solution has been allomothering—which she's writing about. She employed helpers at the nest. And the children have had the benefits of two mothers: Sarah, who's a loving mother, but busy. And a second one, a young woman of good spirit."

"She's a fabulous mother," says Katrinka, a history teacher and crew coach at a boarding school in upstate New York. "She feels bad about the time when she was busy with research, but I don't remember that." When she tells friends that her mother is an expert on infanticide, people often say, "Hey, you're lucky to have survived," but the joke has grown stale. "My cute mom," says Katrinka. "Her theories are pretty modern—she's got all these wild ideas about family, but our own family is kind of traditional—family dinners and everything."

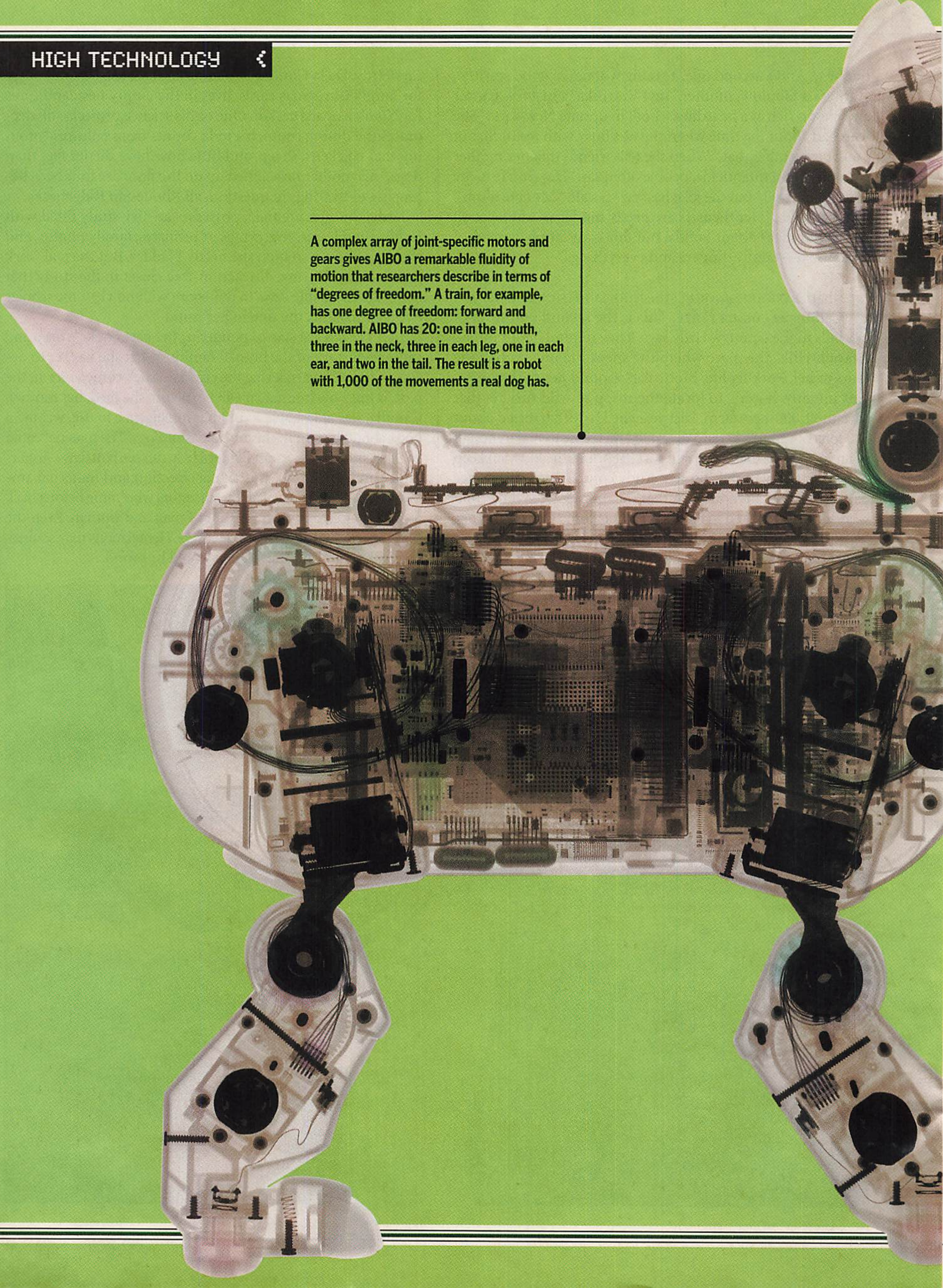
IN THE LATE AFTERNOON, SUNSHINE LIGHTS UP THE NEARBY California coastal range. This is the second oldest set of hills in the country, Hrdy says. They remind her of India's Aravalli Hills, the place where she spent the most satisfying years of her working life. Binoculars around her neck, she listens intently, hoping to locate the troop of wild turkeys that rove the 1,000-acre farm. Last year the Hrdys harvested about 300 tons of walnuts here. "We wanted this place to make enough of an income so that it can support itself, and the kids can keep it," says Hrdy, who has done a study comparing inheritance patterns of daughters and sons. At the moment, the only child who seems interested in farming is their son. "I admit it looks bad," she says. Niko, 16, is away at prep school. Allomother Guadalupe de la Concha "started grieving a year before he left," says Hrdy. De la Concha has taken another job but still poses for family Christmas cards, lives in the empty nest, and cares for Niko's leopard geckos. One of his science projects still decorates the dining room, bacteria counts from cultures "proving that chickens, sheep, and little boys have dirtier feet than dogs," his mother says. Lined up on the floor are four beds belonging to the dogs in question, all Rhodesian Ridgebacks.

Hrdy, the alpha female, possesses an airy study filled with fertility goddesses, engravings of primates, family photos, and shelves of books so high she needs a ladder. But the real work gets done in the tiny, distraction-free closet in the study that her children call the cave. In this room with no view, the scholar lives her real life, the one in her mind.

Here she has just started pondering her next book, "a deep and intimate history of the human family." What she has yet to decide, especially considering the criticism she's come in for in the past, is just how intimate it will be. Before she died, her mother, Camilla, was at last able to put her intelligence to use, writing a book about the family's history and genealogy. The material could be used as research. Sarah Blaffer Hrdy can see patterns—inheritance and patriarchy and sexual selection and maternal ambivalence, all the traits of all the ancestors who came before, back and back and back to the advent of man and woman. Even she may be surprised at what she discovers. Her relations may squirm, her critics may cavil, but Mama would be proud.



Roaming her California farm with one of her Rhodesian Ridgebacks, Hrdy observes a troop of wild turkeys, banded for a student project. They are not langurs, she says, but "they have a similar breeding system."



A complex array of joint-specific motors and gears gives AIBO a remarkable fluidity of motion that researchers describe in terms of "degrees of freedom." A train, for example, has one degree of freedom: forward and backward. AIBO has 20: one in the mouth, three in the neck, three in each leg, one in each ear, and two in the tail. The result is a robot with 1,000 of the movements a real dog has.

Sony's AIBO robotic dog is a peek at a bizarre future when you won't know if a dog—or the pretty girl walking it—is flesh and blood or plastic and memory chips

AIBO SITS PATIENTLY ON FRÉDÉRIC KAPLAN'S office floor. It remains still when Kaplan leans over to switch it on, but it beeps to reassure us it's awake. Then it stirs. Raising its head, wagging its tail, and with all the poise of a Romanian gymnast finishing off a floor routine, it lifts, straightens, and stretches all four legs in unison.

BY CHRISTINE KENNEALLY ◆ PHOTOGRAPH BY GUSTO

When an animalbot is controlled by a human, it's as

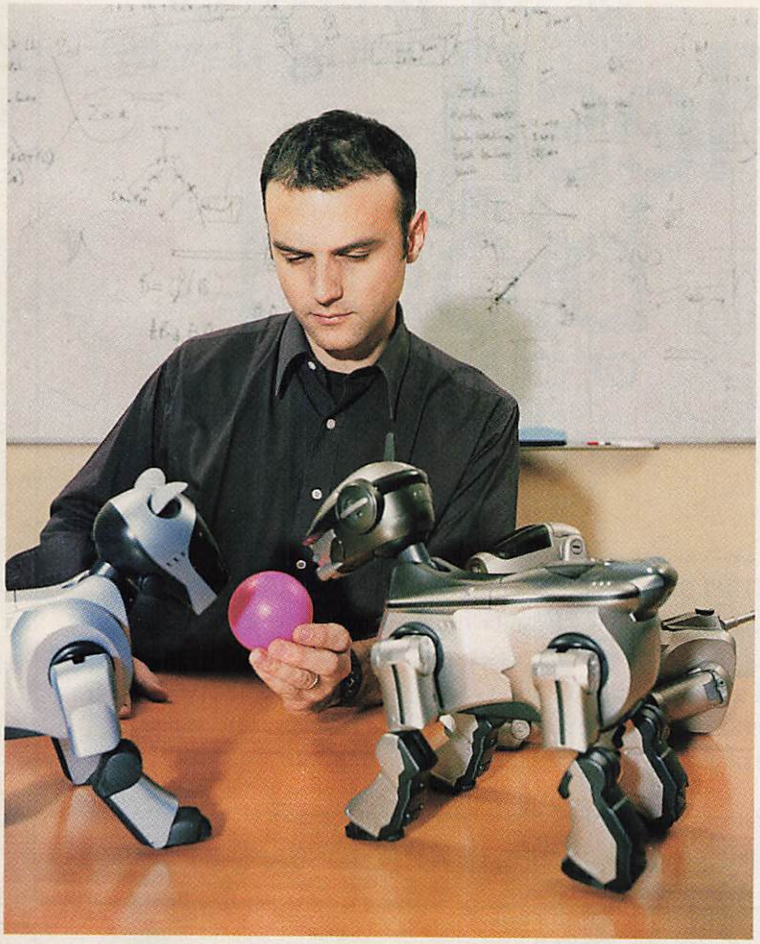
Visually, AIBO is balletic. Aurally, it's arthritic. It creaks and grinds as it raises itself to its feet. But the sound is inconsequential; AIBO is charming. It pads confidently across the floor, and when Kaplan, a young researcher at the Sony Computer Science Laboratory Paris, rolls a red ball before it, AIBO tracks the movement with its head. Good, AIBO, good! It wags its tail and—attaboy, AIBO!—pushes the ball playfully with a paw.

At some level for the human observer, this robot is a dog. That's partly because AIBO—short for Artificially Intelligent roBOt— is a very clever piece of machinery, equipped with a 384 MHz computer processor that coordinates 1,000 different doggy moves, like extending its front paws and luxuriously stretching its back. But AIBO also looks like a dog because I'm human, and humans will believe pretty much anything.

We are wired to see life where it isn't, to impose intelligence where there is none, and to have a wide range of emotional responses to our misguided perceptions. From our ability to bypass disbelief comes anthropomorphism as well as art. Think of all the talking animals in Aesop's fables. Think Miss Piggy. Cognitive scientists are expert at pinpointing all the ways we can make symbolic interpretations or be completely fooled. But what about the perceptions of other animals? What do dogs think of a dogbot?

Recently scientists have been asking themselves just that. When Ádám Miklósi, a Hungarian ethologist who works with dogs and tamed wolves, first came across AIBO, he was struck by the possibilities. He and graduate student Enikõ Kubinyi, both at Eötvös Loránd University in Budapest, contacted Kaplan, and from this meeting arose a series of AIBO-dog experiments with the dual goals of using the real dogs to help them discover better ways to program the robot and using the robot to help them explore the dogs' species recognition: What makes a dog recognize another dog as a dog?

Sony researcher Frédéric Kaplan trains AIBOs from two generations (the one on the left is an older model) to recognize an unfamiliar ball by waving it in front of them. "Each robot develops capabilities unique to itself based on its perceptual and social history," he says.



Even before Kaplan and Miklósi introduced AIBO to Fido, a handful of animal researchers in Europe, the United States, and Japan were busy conducting experiments with their own animal robots, including a flirtatious bowerbird and a furry white ratbot. Animal behavior researchers have used a variety of dummy animals before, ranging from simple red balls of cotton wool designed as stand-ins for robins to elaborate stuffed lions that spooked their real counterparts on the Serengeti last year. But the latest animal robots are more than decoys. They are sophisticated tools that provide a new scientific perspective on the animal kingdom.

When a real animal interacts with an animalbot, and that bot is controlled by a human, it's as though the human has donned a scale-size animal suit and disguised himself as a bird or a dog or even a bee. Because of this, biorobotics behavior experiments promise to reveal intricacies of animal relationships and perceptions that we could only guess at before. The AIBO-dog investigations are especially interesting because of the intimate relationship that exists between humans and dogs. The two species have lived together for more than 14,000 years, and in that time domestic dogs have changed themselves in fundamental ways in order to get along better with us. Dogs aren't just friendly wolves; they think differently, they see the world differently, and they have a new kind of mind because they hang with humans. Exploring this domesticated mind with robots like AIBO allows us to bypass some of our innate human biases. And getting at the real dog's-eye view may end up telling us as much about ourselves as about them.

PHOTOGRAPH BY DARIN MICKEY

though the human has donned a scale-size animal suit

THE STARTLED YELPS CAPTURED ON FILM AT THE END of one of the AIBO experiments are those of the researchers, not the dogs. At the beginning of this film, AIBO stands and then plods guilelessly toward a red plate piled with meat. It is the color of the plate that attracts the dogbot; AIBO is programmed to follow moving red objects with its gaze and to move toward stationary red objects. But it is the food, not the dinner service, that has drawn the Belgian shepherd already crouching on the other side of the plate. AIBO plods, and the shepherd growls. Any other dog would pause at this warning, but the robot just walks ahead, and the shepherd jumps over the plate to attack. Before it could be bitten too hard or suffer any serious damage, Kaplan and his colleagues rushed in to pull AIBO from harm's way. The shepherd got the meat.

AIBO was attacked outright a couple of times in the experiments. (It was also chewed on, bitten, and pushed over.) While this was not the exact response the researchers were after, it was the type of response they were glad to see. Such a reaction, says Miklósi, indicates that some of the dogs see AIBO as more than just a machine.

Identifying another animal as alive, and beyond that, recognizing another dog as a dog, or another human as a human, appears to be wholly instinctive. In fact, it's a complicated combination of identifying certain sights, smells, and behaviors. For each species, the relative contribution of each of these will be somewhat different. The fundamental question driving the AIBO experiments was: Would the dogs recognize AIBO as a living creature? If the answer was yes, the scientists would be one step closer to working out which elements are most important for species recognition.

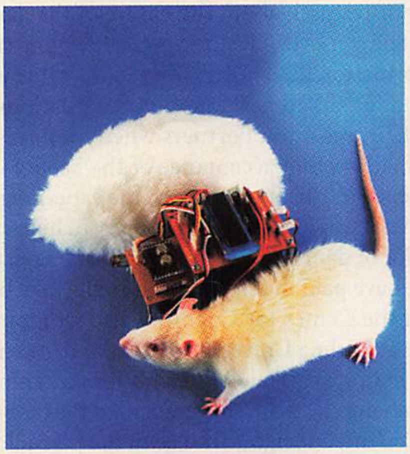
Sorting out the tangle of physical senses and psychological expectations in species recognition will be the work of decades, but Kaplan and Miklósi made a start by looking at what it took for their test dogs to make a few basic distinctions: Is this object alive? Does it look like a dog? Is it worth approaching like a dog?

The scientists set up the experiment using 40 pet dogs (the advantage of which, says Miklósi, is that their owners feed and groom them and also take them home at the end of the day). The test subjects included 24 adult dogs and 16 juveniles. The team put each dog in a room (with its owner but no other dogs), and once ready, AIBO was sent in to see how the dog would react.

The scientists also sent in a real puppy and a toy car, one at a time. The puppy provided an obvious control. The car was used to see if the dogs would react differently to a machine that looks like a dog and a machine that doesn't resemble any living thing but moves at dog speed. In another trial, Kaplan and Miklósi introduced AIBO to the dogs while it was covered in fur that had been stored in a real puppy's sleeping box so it would smell more like a dog.

All four conditions (AIBO, real puppy, toy car, furry AIBO) got the interest of the dogs, but there was a clear ranking of

> ROBOT MENAGERIE <



RATBOT: When the clump of fur (left) covers a ratbot (center) that has been programmed to head to a food source, a real rat (right) will chase it. The ratbot has two arms that allow it to imitate a real rat's standing posture and an FM receiver for communication with a host computer.

BEEBOT: Although the beebot towers over real bees, they follow its "waggle dance" in quest of nectar. The center rod is connected to an X-Y plotter that makes a figure-eight path. The razor blade mimics a vibrating wing, and the plastic sleeve delivers scented sugar water to the bees.

BIRDBOT: The movements of a robotic bird placed in the bower, or courtship arena, of a male satin bowerbird are remotely controlled by a researcher in a nearby blind. The female bot can be shifted from an upright to a fully crouched position (shown above), signaling readiness to mate.

PHOTOGRAPHS: LEFT TO RIGHT, COURTESY OF ATSUO TAKANISHI/WASEDA UNIVERSITY; COURTESY OF AXEL MICHELSEN; COURTESY OF GAIL L. PATRICELLI.

Robot builders have long used biology for inspiration. Now the exchange is more two way

responses. The puppy usually got the most interest from the dogs. The adult hounds were quicker to approach and investigate both the furry bot and the real puppy than either the non-furry robot or the car. Even though the dogs still showed a preference for the non-furry AIBO over the car, the addition of fur evoked the strongest response of all the artificial stimuli.

The team also measured when the dogs growled at their guests. Again, the dogs responded to the real puppy and the furry AIBO in a similar way, growling at both in most situations, but not as much at the other objects.

Introductions between canine and machine took place in two basic experimental settings, one with food and one without. The food seemed to make the identity stakes higher. With meat around, the dogs growled a bit at the furry robot but much more at the real puppy, perhaps recognizing that one posed more of a threat to their meal than the other. Nevertheless, the adult dogs still showed more interest in both the real puppy and the furry AIBO, investigating them sooner and for a longer time than the other objects.

The strongest distinction between AIBO and the toy car was made by the younger dogs when there wasn't any food around. From an objective standpoint, AIBO has far more in common with the car than it does with another dog. Still, the young dogs growled at the robot dog (whether or not it had fur) and also at the puppy but not at the car.

Did the dogs see AIBO as another dog? The short answer is yes. They approached it more the way they did the puppy than the way they approached the car. Although the dogs worked out pretty quickly that AIBO wasn't another dog (it didn't move fast enough), at the outset its basic body shape, the way it moved, and especially the fur piqued their interest.

So much for the romantic idea that canines have primitive smarts that humans, in all our civilized glory, have lost. We assume that dogs have the natural ability to smell the real from the fake, but it's beginning to look as if they can be fooled in the same kinds of ways that we can.

And it's not just dogs. Other scientists are disguising themselves, like wolves in sheep's clothing, and learning what it takes to cheat all sorts of animals. Unsurprisingly, the less like us the animal is, the less similarity there is between what it takes to pull the wool over our eyes and what it takes to pull the wool over theirs, if they have any.

IN THE LATE 1980S AND EARLY 1990S, AXEL MICHELSEN AT ODENSE University in Denmark ran a series of experiments using a robot bee. The beebot was made of a brass body and some wires covered in beeswax and connected to some motors. It was 13 mm long (the same as a worker bee) and 5 mm wide (a little broader). A cheap razor blade broken in half stood in for the wings.

It didn't look like a bee; it didn't feel like a bee; and before it was put in a hive, it didn't smell like a bee. From a human perspective, the beebot was little more than a small switch with wire sticking out of it. But it worked pretty well.

The beebot was placed on the hive's dance floor and programmed to simulate a complicated "honey dance." Bees use this dance to map the location of food for one another. The overall pattern of the dance is two adjacent ovals connected by a straight line called a waggle run, during which a female bee swings her abdomen back and forth like a pendulum, 13 to 15 times a minute. The upward angle of the line represents the direction of the nectar in relation to the sun, and the duration of the waggle run indicates distance.

This odd-looking beebot was acceptable to the hive's inhabitants for a number of reasons. The inside of a hive is completely dark; bees don't see the dance at all. Bees don't hear the dance either. "There's no indication that bees can hear in the traditional sense of the word," Michelsen says. "They don't have a pressure-sensitive ear." So for the residents of the hive, the beebot was more bee than bot because of its dance moves.

Other researchers have argued that bees decipher the honeycomb vibrations generated by the dance to determine the location of nectar. But Michelsen's experiment suggests the bees are responding to oscillations of air created by the dance moves. In any case, bees decoded his waggling robot's dance correctly and found the scented baits that he had planted.

Did the bees think the bot was another bee? For all practical purposes, they accepted it. This gave Michelsen an opportunity to confirm what prior research about the nature of the dance could only suggest: Some moves, like the upward wagging run, conveyed more information than others. And in the same way that the dogs responded differently in different situations—growling more at their metal test partners when food was at stake—Michelsen believes that acceptance of the beebot depended on the context. He attributes some of the experiment's success to the fact that it was low season for nectar. In high season, when there's a lot of dancing to compete with, he says, the real bees would not have paid much attention to the fake bee.

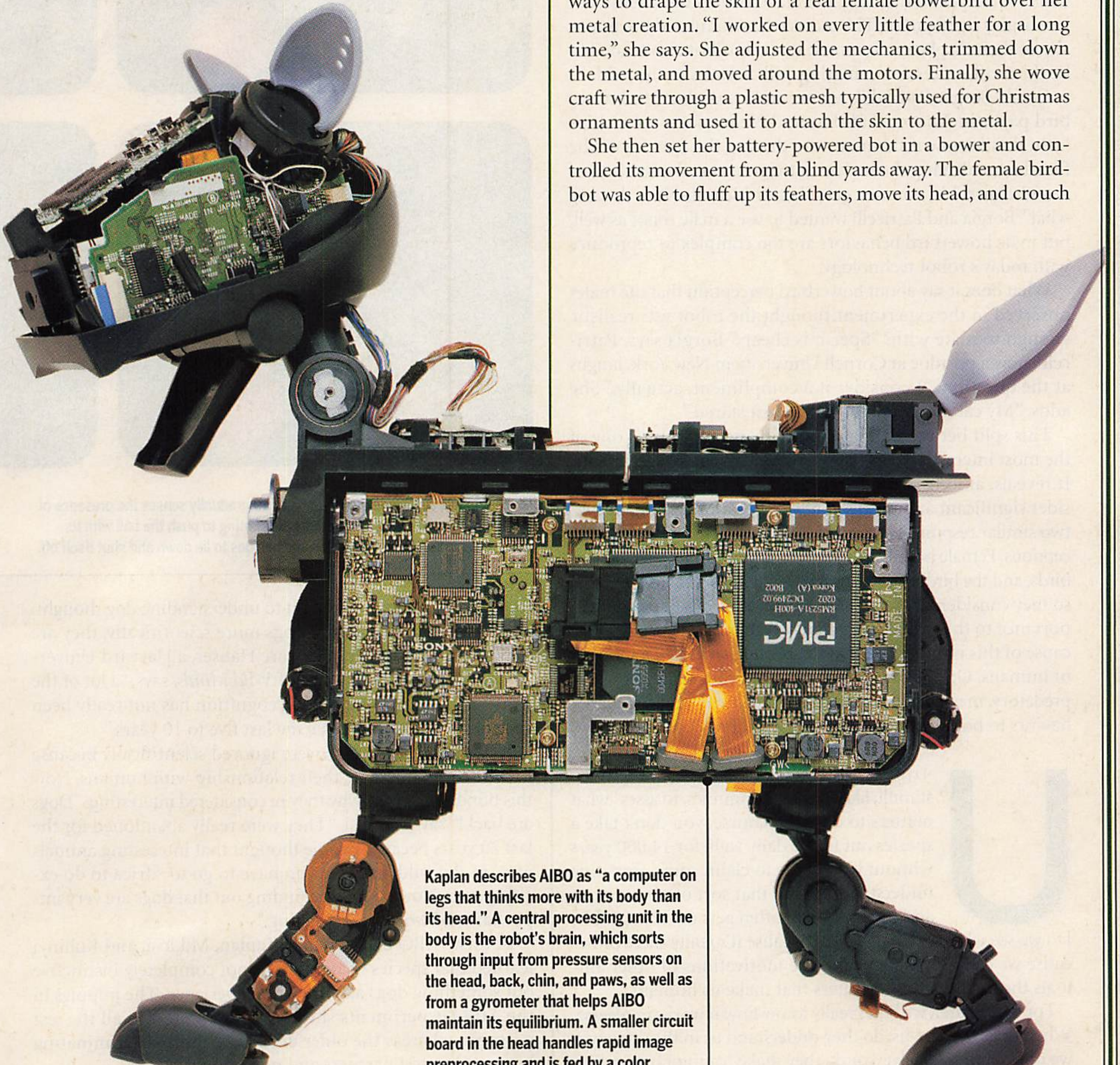
Barbara Webb, at the Center for Cognitive and Computational Neuroscience at Stirling University in Scotland, recently published the first major overview of biorobotics in animal behavior. After surveying the field, she concluded that robotics can offer unprecedented insights into both the physiological and behavioral workings of an animal.

Robot builders have used biology for inspiration and ideas for a long time. But now the exchange is becoming more two way. The new systems being built, says Webb, "answer questions for biologists as well as engineers." So great is the potential of robotics to answer questions in animal behavior research, she says, it may amount to an entirely new methodology that promises to be incredibly useful because robots must operate in the real world, responding to challenges that real animals respond to (walking, seeing, being bitten). When you build a bot and repeatedly test it out, Webb says, "you learn something about the real environment that you can overlook very easily."

In addition to exposing the intricacies of species recognition and communication, robots can be used to investigate predator-prey relationships, as well as attack responses and mating habits in mammals, insects, and birds. For her Ph.D. at the University of Maryland, Gail Patricelli took a birdbot into the Australian rain forest to analyze the sexual selection of bowerbirds. Like Michelsen's beebot, Patricelli's robot was built from scratch. She sat down with a mechanical engineer and watched videotapes of real bowerbirds. They broke down the movements into different planes that could be re-created with servomotors and then built a metal frame with a computer chip that responded to a remote control.

Patricelli and her research team spent a month and a half in a little shack in the middle of the rain forest trying to find ways to drape the skin of a real female bowerbird over her metal creation. "I worked on every little feather for a long time," she says. She adjusted the mechanics, trimmed down the metal, and moved around the motors. Finally, she wove craft wire through a plastic mesh typically used for Christmas ornaments and used it to attach the skin to the metal.

She then set her battery-powered bot in a bower and controlled its movement from a blind yards away. The female birdbot was able to fluff up its feathers, move its head, and crouch



Kaplan describes AIBO as "a computer on legs that thinks more with its body than its head." A central processing unit in the body is the robot's brain, which sorts through input from pressure sensors on the head, back, chin, and paws, as well as from a gyrometer that helps AIBO maintain its equilibrium. A smaller circuit board in the head handles rapid image preprocessing and is fed by a color camera and an infrared distance sensor.

PHOTOGRAPH BY GUSTO

by rising up and tilting forward; crouching signals to a male bowerbird that a female is ready to mate. Because the robot allowed Patricelli to simulate female behavior, she was able to measure the male response.

Patricelli's robot showed with its movements that female bowerbirds control the intensity of male mating displays. If the female indicates, with fluffing and crouching, that she's comfortable and won't be scared away, the male increases the intensity of his mating behavior (puffing of feathers, extending the wings, running, and making buzzing noises). If the female reduces her crouching, the male reduces the intensity of his display in response. The males who modulated the intensity of their displays in response to the birdbot also tended to be the most successful in mating with females in the wild.

Gerald Borgia, Patricelli's adviser and a coauthor of a bowerbird paper in *Nature,* said that in these intricate courtships "you don't know if the males are driving the females or the females are driving the males. But if you can take one end of it and control it, you can get a better idea of who's driving what." Borgia and Patricelli wanted to use a male robot as well, but male bowerbird behaviors are too complex to reproduce with today's robot technology.

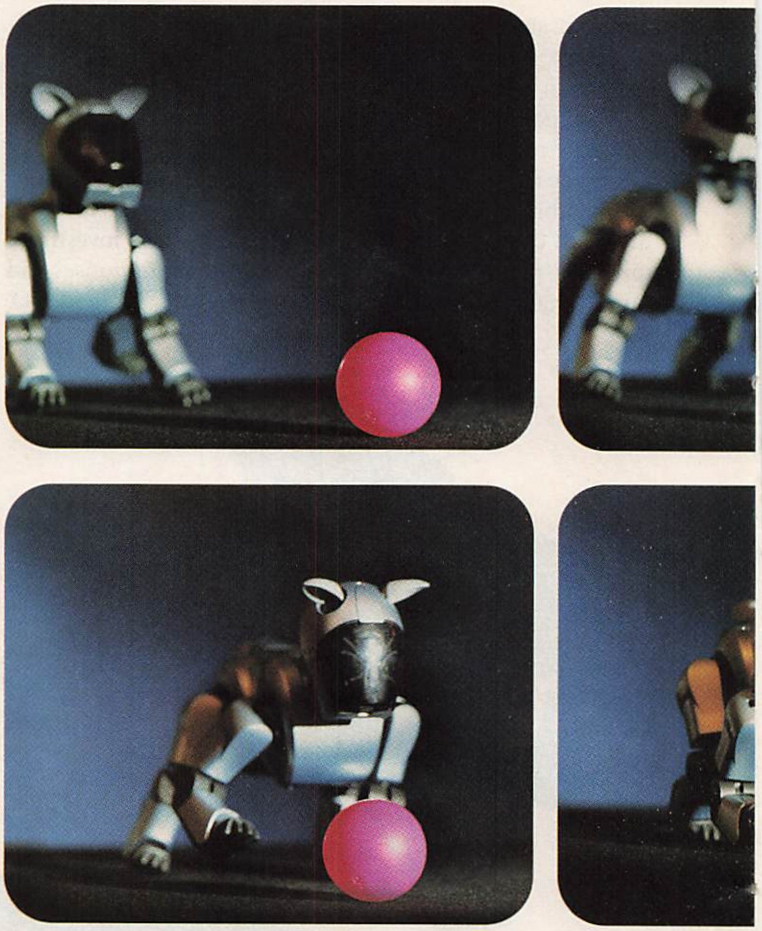
What does it say about bowerbird perception that the males observed in the experiment thought the robot was realistic enough to mate with? "Sperm is cheap," Borgia says. Patricelli, now a postdoc at Cornell University in New York, laughs at the question. "I consider it a compliment, actually." She adds, "My cat didn't fall for it. She just stared."

This split between different species' perceptions is one of the most interesting parts of the robot behavior experiments. It reveals, among other things, what different animals consider significant and what's beneath their notice. Sometimes, two similar responses are inspired by completely different perceptions. Female bowerbirds are very important to male bowerbirds, and the birdbot met enough of the males' mating criteria, so they considered it real. A female bowerbird is of far less importance to the casual human observer, and it is perhaps because of this indifference that the robot also fooled a number of humans. On the other hand, the cat, whose intentions are predatory, may need to see different qualities and different behaviors to bother expending energy on the robot.

UNTIL RECENTLY, SCIENTISTS HAVE HAD LIMITED stimuli, like videos or dummies, to assess what matters to dogs. Of course, you don't take a species out for its daily walk for 14,000 years without being able to claim some empathic understanding. But that sort of observation and introspection often gets us into trouble. Do we see what we think we see because it's really there or because we can only understand the motivations of other animals through the muddy filters that make us human?

For that matter, we don't really know how it works in reverse. When dogs observe us, do they understand us in the same way we understand ourselves, or do they make "caninopomorphic" assumptions about the behavior and motives of humans?

By using AIBO, Kaplan and Miklósi removed some of these



While taking a stroll in the laboratory, AIBO gradually senses the presence of a ball it has seen before. After briefly attempting to push the ball with its paws and head, AIBO is distracted and decides to lie down and shut itself off.

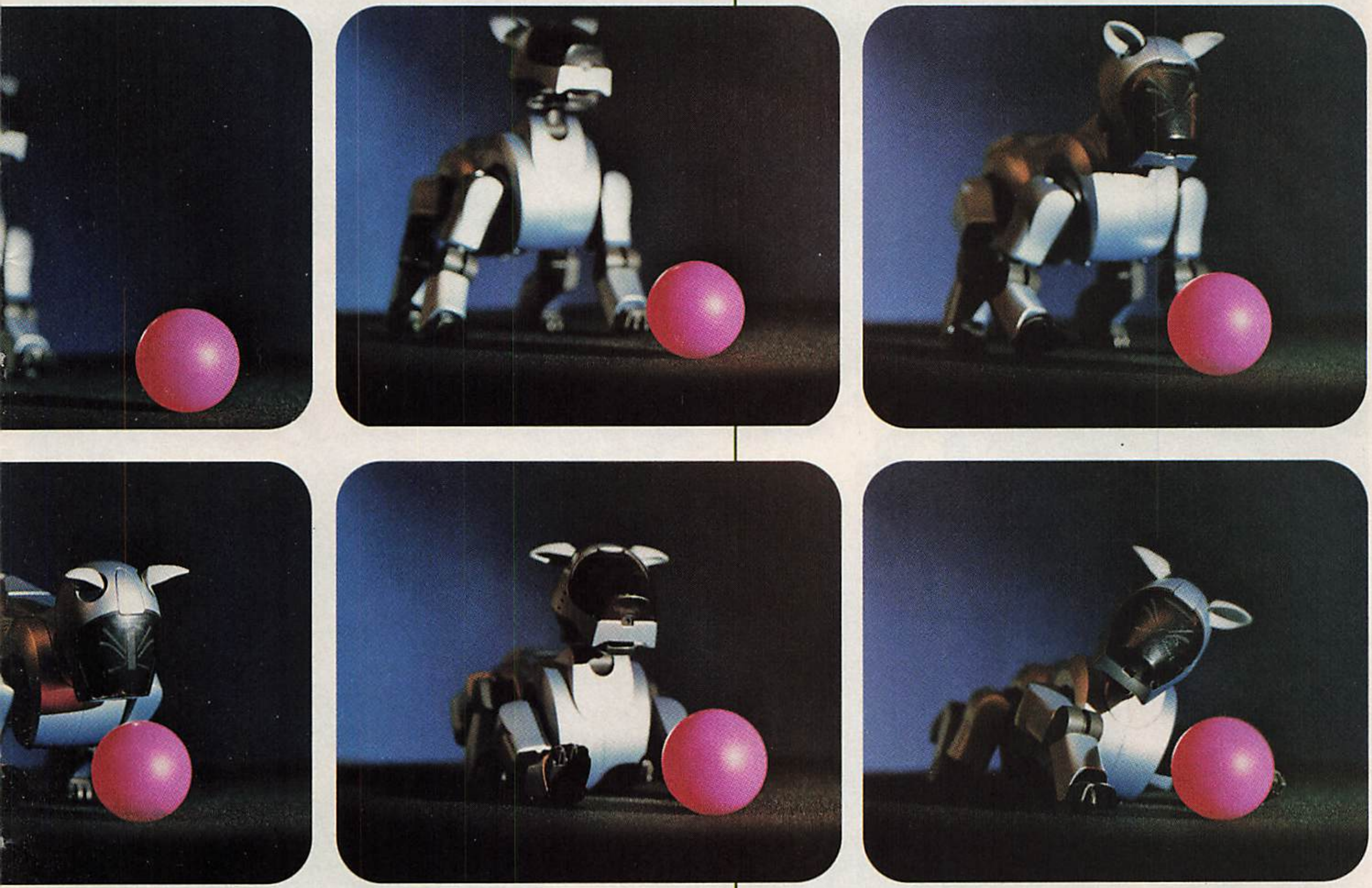
innate biases typically brought to understanding dog thought. In their efforts to measure dogs more scientifically, they are at the forefront of a trend. Marc Hauser, a Harvard University biologist and the author of *Wild Minds,* says, "a lot of the work that's been done on dog cognition has not really been careful science until maybe the last five to 10 years."

It used to be that dogs were ignored scientifically because no one could untangle their relationship with humans. Now this bond is precisely why they're considered interesting. "Dogs are back!" says Miklósi. "They were really abandoned for the last 20 years because people thought that interesting animals were in the wild and that you have to go to Africa to do exciting stuff. Now people are finding out that dogs are very important and worth investigating."

In their AIBO experiments, Kaplan, Miklósi, and Kubinyi learned that species recognition is not completely instinctive but something dogs acquire with experience. The puppies in the AIBO experiments showed more interest in all the test partners, whereas the older dogs were more discriminating between live test partners and nonliving partners.

The crucial factor in the dogs' eventual loss of interest was AIBO's lack of speed. The dogs would approach, make a play

PHOTOGRAPHS BY DARIN MICKEY



gesture, and wait a second. Because AIBO didn't respond, they gave up straightaway. If AIBO started to move again, the dogs showed interest again, but the same thing would happen. The bot just didn't interact. The lesson is this: If you want to be accepted as a dog, you have to move at a dog's pace and respond to dog cues, such as play behavior.

The scientists also confirmed that the dogs' species recognition was not an automatic judgment. Dogs use several senses, including vision, hearing, and smell, to identify other dogs as dogs. They approach each other with a particular orientation and then use their senses hierarchically, switching from one to another in greeting. The visual, like basic body shape and movement, piques their interest, then the sniffing commences. First a sniff at the rear end: Are you a dog? Then a sniff at the front end: Are you a dog? And on it goes.

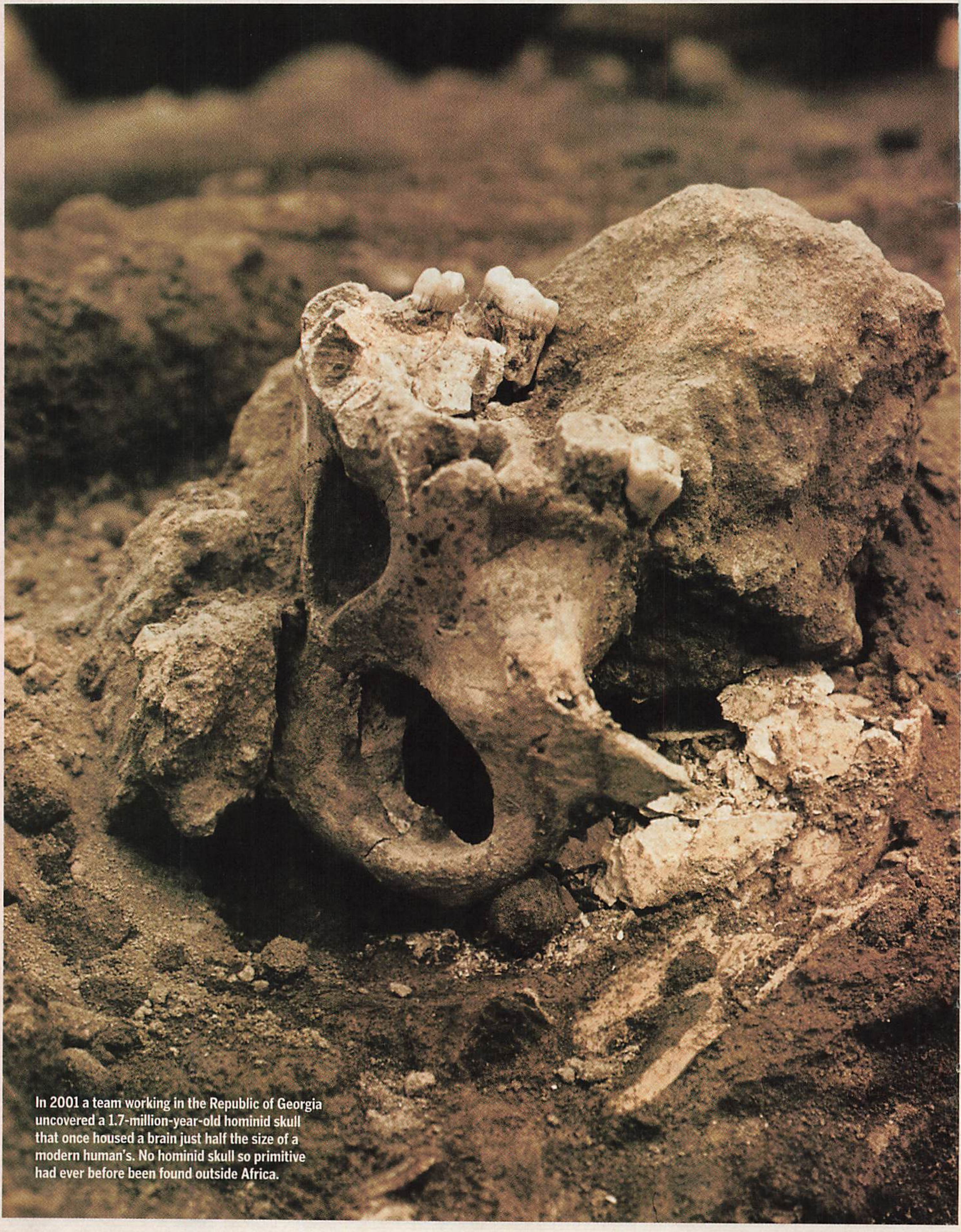
Of the senses, vision mattered more in the AIBO experiments than most people might expect. "Dogs are not 100 percent smell, in contrast to what people believe," says Miklósi. He argues that while dogs have excellent olfactory abilities, they compromised some of these natural talents in order to live with humans. Basically, he says, "humans are a dog's environment." Although they still smell as sharply as their wolf forebears, dogs have also developed the ability to interpret visual cues from species other than their own. This is one of the legacies of their evolution in a domestic setting; it's more useful to observe communicative signals from humans than it is to smell them.

These findings are clues to how much we can learn about ourselves from studying dogs. Because we are the dogs' environment, their evolutionary changes emphasize just how important visual information is to us.

It may be that some qualities of our behavior or environment are as fundamental to us as vision, but we may not have sufficient perspective to know that. If we can examine ourselves from a distance, in this case from a canine point of view, such traits may come to light and surprise us.

THE DUSTY REMAINS OF JEAN-JACQUES ROUSSEAU LIE IN A CRYPT TWO blocks from Sony's labs in Paris. "Rousseau!" Kaplan exclaims, shaking his head at the legacy of the 18th-century philosopher. As the father of the romantic movement, Rousseau had a talent for glorifying nature. He advocated passion over reason and believed that humanity's truest and happiest state was a primitive one. Civilization was considered a corrupting force. "Romanticism was terrible for the machines," says Kaplan ruefully.

But like its founder, the movement against machines is truly dead. Animal-like machines may unlock what Rousseau valued most—the mysteries of the natural world and the uncivilized mind. And although Miklósi was ultimately disappointed in AIBO's performance in the laboratory—a really effective dogbot will have to move faster—his experiments show the way to new horizons of scientific knowledge by giving us the chance to inhabit another animal's hide. ☒



In 2001 a team working in the Republic of Georgia uncovered a 1.7-million-year-old hominid skull that once housed a brain just half the size of a modern human's. No hominid skull so primitive had ever before been found outside Africa.

Survivor

Older, more primitive skulls from Eurasia and Africa are changing what we thought we knew about where we came from By Richard Stone

THREE HUNDRED FEET BELOW THE ash gray ramparts of a crumbling fortress, two rivers merge in a verdant valley and sweep eastward to the Caspian Sea. It's easy to see why Georgian royalty would have established a stronghold on this basalt bluff along the old Silk Road in southwestern Asia 1,000 years ago. It's also clear how this mild region, sheltered by mountains from the cold steppes to the north and from arid plains to the south, would have appealed to a band of human ancestors who may well have been the first to venture out of Africa nearly 2 million years ago. What is not at all clear, muses paleoanthropologist David Lordkipanidze, is how those primitive wanderers could have traveled here in the first place.

Lordkipanidze, the deputy director of the Georgian State Museum in the Republic of Georgia, has reason to wonder. In the last three years, he and his team at Dmanisi have unearthed four hominid skulls—ancient human forebears at least 1.7 million years old. No hominids so ancient have ever been found outside Africa. Stranger still are their features: apelike brows, humanlike teeth, and most amazing of all, a brain roughly half the size of our own.

Which leads to the biggest puzzle for Lordkipanidze: Anthropologists have always assumed small-brained hominids lacked enough intelligence to create the tools they'd need to fan out from their African homeland and survive in new habitats. The remains of these ancient wanderers should not be here—unless our conception of the origin of modern humans is wrong.

The skulls from Georgia are not the only hominid remains rewriting our history. Last July, researchers in central Africa unveiled an emissary from the time when our ancestors split from chimpanzees some 7 million years ago. That skull poses even more questions. First, it was found in Chad, 1,500 miles from the East African Rift Valley, long the presumed center of hominid evolution. Second, the area where the skull was found was once forest, not the primordial wide-open savanna where hominids and their hallmark bipedalism were thought to have evolved. Third, and perhaps most surprising, the skull is nearly twice as old as any other hominid skull ever uncovered. It is 2 million to 3 million years older than *Ardipithecus ramidus*, the Ethiopian fossil thought to be the earliest exemplar of the transition from ape to hominid. "It's a revelation," says Fred Spoor, professor of evolutionary anatomy at University College London. "The blueprint for our common ancestor is gone."

The Chad and the Dmanisi skulls, says Bernard Wood, a paleoanthropologist at George Washington University in Washington, D.C., "have upset traditional views about the origins of hominids and about the origins of *Homo*," the genus to which humans belong. The story of human evolution no longer looks like a smooth, gradual transition from ape to hominid. Instead it resembles an eons-old game of *Survivor*, with multifarious contenders popping in and out of the fossil record.

"These hominids were coming off the production line in a mix-and-match sort of way," says Wood, which forces researchers to revisit a fundamental question: What is a hominid? Or to phrase it another way: Which of these creatures are our ancestors, and which are also-rans?

One conviction has held firm since the days of Charles Darwin: Hominids descended from apes. Starting around 11 million years ago in the subtropical forests of Eurasia and, most likely, Africa, the great apes effloresced in an array of shapes and sizes. But within a couple of million years, the vast inland Tethys Sea, which extended across southern Europe, dried up. The Plateau of Tibet thrust up, and forests began a steady retreat toward the equator. That was bad news for the great apes. "They started to bite the dust," says Rick Potts, director of the human origins program at the National Museum of Natural History in Washington, D.C. Although a dearth of great-ape fossils makes it hard to reach conclusions, it appears that, beginning about 7 million years ago, the range of the last of the great apes was limited to Africa and Southeast Asia.

Not long afterward, some enterprising individuals evolved the ability to walk upright. How and why remains one of evolution's great mysteries. A longstanding theory held that bipedalism evolved only when early hominids needed to survive in a changing habitat. As the forests of Africa shrank, the theory suggested, bipedal hominids emerged who could move more freely while foraging on the expanding savanna.

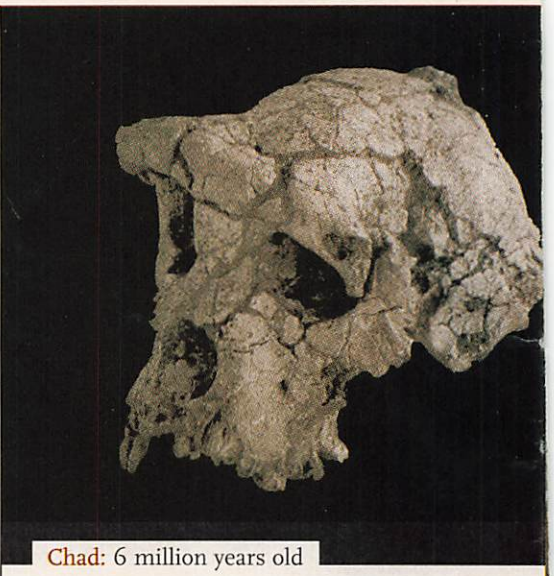
Another defining hominid feature is the presence of small canine teeth. Anthropologists guess that their emergence accompanied a change in foraging habits that led to hominids walking upright.

This story was pieced together based on hominid finds in Africa's Rift Valley. But the skull found in Chad hints at a different, far more complicated history. "Could Chad represent its own little cauldron of experimentation in human evolution?" asks Potts. "Yeah. And that's really exciting."

THE CHAD SKULL WAS DISCOVERED IN JULY 2001 in the Djourab Desert by Ahounta Djimdoumalbaye, a student from the University of N'Djamena in Chad who was working under paleontologist Michel Brunet of the University of Poitiers in France. "To my great surprise, it was nearly complete," says Brunet.

His team members contend that the skull's original owner—nicknamed Toumaï, which means "hope of life" in the local language—was a hominid, most likely a male. They make their case based on Toumaï's small canines, short lower face, and the forward position of an indentation in the cranium where the spinal column connects to the head, indicating a head held upright.

Bernard Wood imagines glimpsing Toumaï in the flesh. "From the back, you might have mistaken him for a chimpanzee," he says. Head on, however, he would have been far more interesting. Eyes set wide like a gorilla's and a heavy browridge level with the top of the skull suggest an ape. Suggesting a human are the modestly sized lower face, a short snout like an early *Homo* from a couple of million years ago, and petite canines that fit snugly against the incisors, just as they do today. "If it's not a hominid, it's something that's damn near one," Wood says.



Chad: 6 million years old

Yet Toumaï may not have been a biped. Another bit of paleo-phrenology suggests he possessed the huge neck muscles of a bodybuilder or, as some claim, a female gorilla. The skull "has a whopping big crest for the connection of neck muscles," Potts says. That brawny neck could have kept a head upright for an ape loping on all fours. "You get the sense that it's really close to the branching point [the last common ancestor between chimpanzees and hominids]."

Without more of the creature's skeleton—particularly a crucial leg or foot bone, or remains of kin—no one can be certain Toumaï walked upright. Brunet argues that the canines alone make it a

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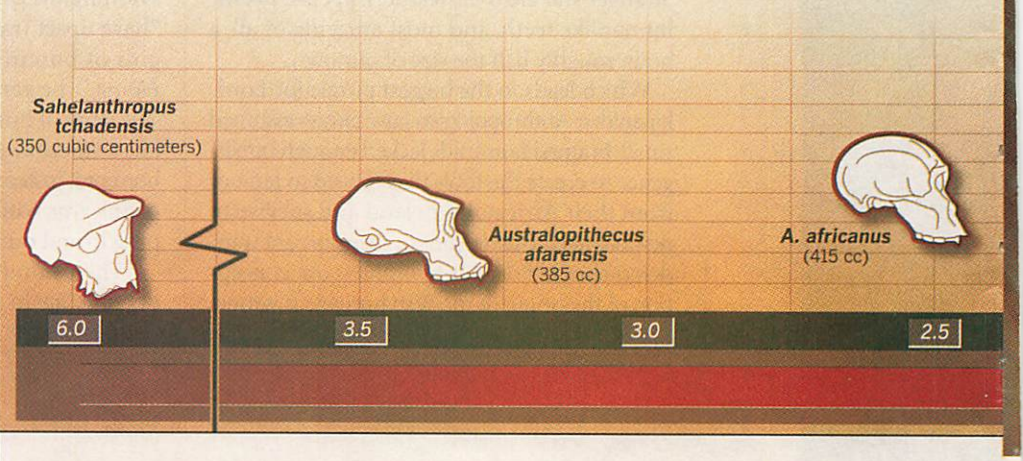
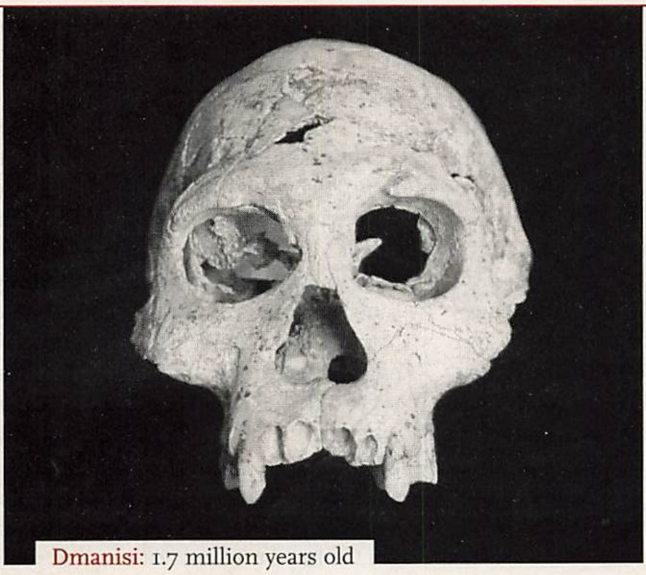
SKULLDUGGERY

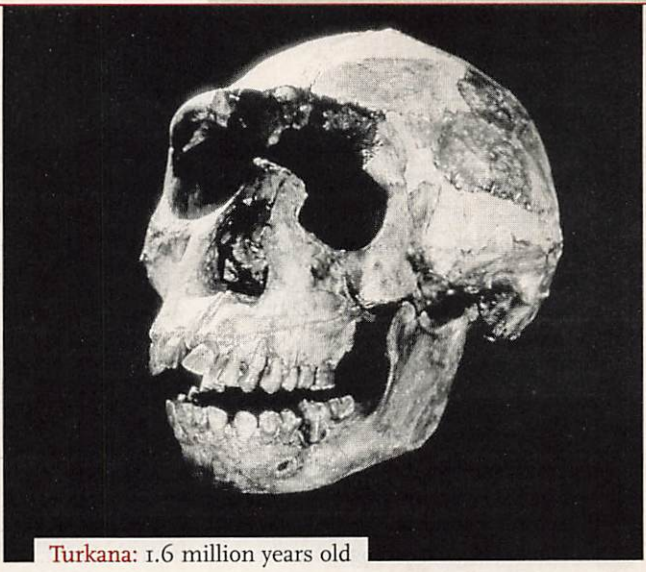
For their size, humans have larger brains than all other animals except dolphins and whales. The emergence of larger brains appears in the fossil record, summarized at right. The Chad skull (*Sahelanthropus tchadensis*) held a brain less than one-third the size of a modern human's. Over time, hominids lost the wide flat teeth for grinding plant food. Their brains got bigger as their teeth got smaller. Presumably, bigger brains allowed them to forage more effectively.



GRAPHIC BY MATT ZANG



Dmanisi: 1.7 million years old



Turkana: 1.6 million years old

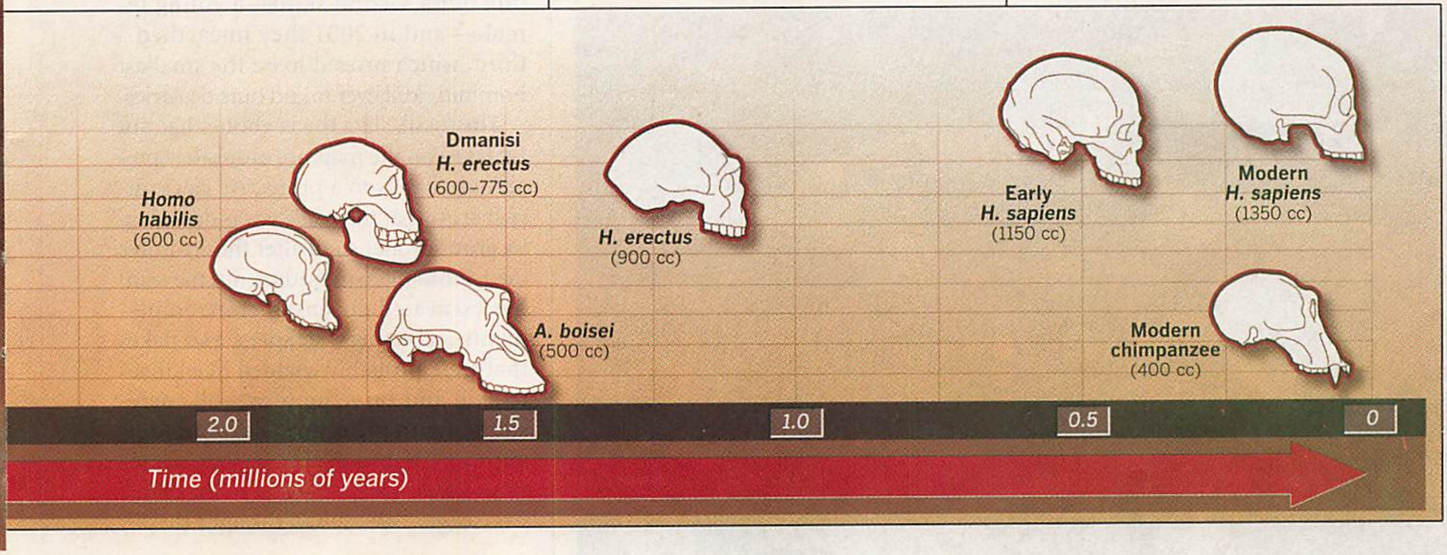
The Chad skull has the thick browridge of a gorilla, but the rest of its face resembles hominids one-third its age. The Dmanisi skull, which belonged to a young person, is one of the most primitive skulls ever attributed to the genus *Homo*. By contrast, some paleontologists note that a child resembling the 12-year-old Turkana boy—an *H. erectus* skeleton found in Kenya—might pass unnoticed among us if a cap covered his low forehead and heavy brows.

strong candidate for a hominid. Until Toumaï was found, such dentition was thought to have originated in australopithecines, as many as 2 million to 3 million years after Toumaï lived. These heavy-jawed hominids, presumed to be human ancestors, arose in Africa about 4 million years ago and include the famous 3.5-million-year-old skeleton named Lucy.

Toumaï is not the only fossil vying for the title of earliest hominid. Two years ago, Martin Pickford and Brigitte Senut of the College of France unveiled a clutch of 6-million-year-old fossils unearthed in Kenya's Tugen Hills. The remains, named *Orrorin tugenensis*, are just a few fragments of limbs and the lower jaw and some teeth. Nonetheless, the discoverers contend that *Orrorin*'s molars—small and thickly enameled like our own—look hominid. So does its femoral head, the rounded end of the leg bone that fits into the pelvis. The bone appears robust enough to hold a torso upright. The specimen's only shortcoming, though, is glaring: Unlike the teeth in the Chad skull, *Orrorin*'s canines are not only larger than our own but grooved like those of a chimpanzee.

Not surprisingly, some experts say *Orrorin* was a chimp. The argument is fueled more by vitriol than evidence, as there is no fossil record for chimpanzees. "We badly need to find what people are desperately trying to say that they haven't found, which is a fossil chimpanzee," says Wood. Biological anthropologist Leslie Aiello, dean of the graduate school at University College London, urges caution as well. "How do we know that any of the recent finds are on the line to modern humans?" she asks.

Another fresh set of fossils from the northern Rift Valley, in Ethiopia, has only added to the confusion. Perhaps 5.8 million years old, the jawbone, teeth, and other fragments belong to a species of the ancient *Ardipithecus* line. This candidate's canines look more like our own. The shape



of a well-preserved foot bone hints at an upright posture. Until recently, one of this specimen's presumed descendants, 4.4-million-year-old *Ardipithecus ramidus,* held the title of earliest known human ancestor. "A couple of years ago, quite a number of us were simply waiting for *Ardipithecus* to tell us what it was all about. We thought that it would be the most primitive hominid," Potts says. "All this mixing and matching [of traits] suggests a lot of population isolation, independent evolution, and coalescence of populations again. It's going to be really difficult to figure all this out," he says.

Daniel Lieberman, a biological anthropologist at Harvard University, agrees. There are but a few dozen hominid skulls more than 1 million years old, and skulls don't reveal much about evolutionary relationships. "You don't inherit bones from your ancestors; you inherit their biochemistry," he says.

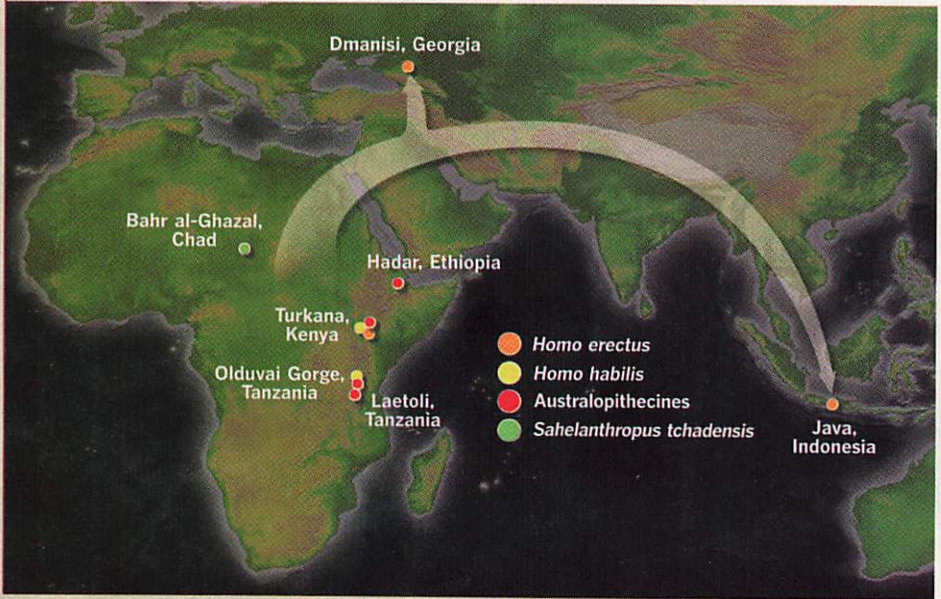
While scholars can easily dispute the meaning and classification of hominid finds in Africa, the discoveries in Georgia are provoking near-unanimous wonder and bewilderment. Almost a million years older than any hominid remains found in Europe, they are forcing scholars to rethink not only what constitutes an early human but how those early humans left Africa and peopled the globe.

JULY 8, 2002: IT'S OPENING DAY AT FIELD Two in Dmanisi. Everyone buzzes with anticipation, oblivious to the pitter-patter of drizzle on a blue tarp stretched overhead. *Thump, thump, thump.* The ground grunts hollowly as a worker whacks it with a rock hammer. A few feet away, others gently but insistently scrape away soil that has remained undisturbed since the early days of the Pleistocene Epoch, 1.8 million years ago. A trio of Georgian men labor on the edge of the shallow pit, using trowels to remove clumps of earth from around wishbone-shaped antlers and the yellowed bone of a prehistoric beast.

The crew has started late this season, but hopes are high. At this site during the summers of 1999 and 2001, they unearthed three skulls and other bones classified as *Homo erectus,* a single rung down the species ladder from *Homo sapiens.* The fossils discovered so far in these sediments pose a riddle that only further bone discoveries might solve.

The first hint that Dmanisi had a history running far deeper than its former life as a medieval trading post came in 1983, when a paleontologist working at the obscure site unearthed the tooth of a rhinoceros, an animal that had vanished from the region during the Pleistocene. The very next year, researchers found a stone chopper. "It was a piece of luck. Such tools are so primitive that it could have easily been missed," says Lordkipanidze.

Paleontologists infer the evolution of various hominid species and the migration of *Homo erectus* out of Africa from remains in the fossil record. The 6-million-year-old skull found in Chad is now the oldest contender for first hominid. A few years ago, the oldest candidate was believed to be from Ethiopia.



GRAPHIC BY MATT ZANG

The chopper convinced the team that beneath the ruins of the Silk Road fortress lay remains from a distant era. In the years that followed they discovered more fossils of animals, including saber-toothed cats, hyenas, giraffes, and ostriches. Such fauna was known to have existed in Europe more than 1 million years ago—but it was a big unknown whether the chopper dated from that period. The intrigue deepened in 1991, a turbulent year when Georgians fought for independence from the Soviet Union. On the last day of excavations that summer, a student found a human mandible, or jawbone, in the Pleistocene sediments. "That year," says Lordkipanidze, "Georgia became important for paleontology."

At the time, Dmanisi's place in paleohistory was far from secure. At a major meeting in Frankfurt, Germany, that December, the dig's leader, Leo Gabunia, and his protégé, Lordkipanidze, displayed the jawbone, which they were carrying in a tobacco tin, to a few giants of paleoanthropology. It was a humbling experience for an awestruck neophyte. "There was a lot of skepticism," Lordkipanidze recalls. "The mandible was so well preserved, many people said it had to be modern."

Then, after a heavy rain in May 1999, a glint of bone protruding from the sediment caught the eye of a Georgian archaeology student. The Dmanisi team had found the skull of an adult male hominid. Later that summer, the team dug out a second skull—a young female—and in 2001 they unearthed a third, which proved to be the smallest hominid skull ever found outside Africa.

The fossils, like the jawbone that put Dmanisi on the map, are exquisitely preserved, thanks to a protective calcium-rich crust that most likely was deposited by groundwater soon after the creatures died. From the same sediments, the team has excavated dozens of stone implements—choppers, scrapers, and flakes that were probably wielded like knives to skin and carve up prey—all corresponding to primitive Oldowan tools used by African *Homo erectus,* sometimes called *Homo ergaster,* in the Olduvai Gorge. "We all had thought that in

Excavations at the Dmanisi site in the Republic of Georgia began in 1936. In the late 1980s archaeologists found stone tools of the sort used by early hominids in Africa. By 2001 traces of 1.7-million-year-old hominids turned up, challenging the conventional time line of human migration out of Africa.

PHOTOGRAPH BY GOURAM TSIBAKHASHVILI.

order to get yourself an exit visa from Africa," says Wood, "you needed to have a largish brain and pretty sophisticated tools." Dmanisi demolished that notion.

But the skulls and tools raised still more questions. The skull found at Dmanisi in 2001 had primitive features, such as huge canines and a prominent browridge, which suggested it might not belong to *Homo erectus*.

"At first look," says Lordkipanidze, "everybody said it was *Homo habilis,*" a long-armed, squat hominid thought by many to have given rise to *Homo erectus*. Nobody imagined that *Homo habilis* possessed the brains or the legs for long-haul travel. Now people aren't so sure and eagerly await bones from other parts of the creature's body. "It's really going to be a dilemma if they come up with a *Homo habilis* body to go onto the *Homo habilis* head," says Potts.

"We've always thought you could only have this sort of head with this sort of limbs," says Wood. "I suspect that notion is going to get blown out of the water."

A revelation will have to wait at least another year. Last year Lordkipanidze's team found another skull in a block of clay sediment, but it wasn't extricated before *Discover* went to press. The search continues for parts of the skeleton that could tell us more.

A QUESTION STILL TROUBLING RESEARCHERS IS how far the bold, small-brained people of Dmanisi got in their trip out of Africa. They would have had good reason to hunker down at Dmanisi: Notwithstanding saber-toothed cats and other hazards of Stone Age life, "it was probably quite comfortable here," says Lordkipanidze. He thinks the region had ample water and a mild climate. A fine place, perhaps, for a pioneering population to settle down and flourish.

Perhaps Dmanisi was a launching pad for later human evolution. A smattering of hominid fossils from Eurasia, beguiling in their paucity and uncertain dating, support the idea that the Dmanisi pioneers could have fanned out across the continent. And lurking in the rain forest thousands of miles to the east are traces of Java man, the *Homo erectus* skullcap discovered in 1891 that could be as much as 1.9 million years old. Differences in bone shape between Dmanisi and Java fossils seem to rule out a direct link, but a more circuitous connection might have been made through other early hominid populations outside Africa. Primitive stone tools about 1.4 million years old, for example, have been found in Ubeidiya, Israel. Perhaps traces of the migration lie in the Himalayas or Afghanistan, or other remote regions. "You're going to get some really intrepid people going in and exploring areas that haven't been explored before," Potts says.

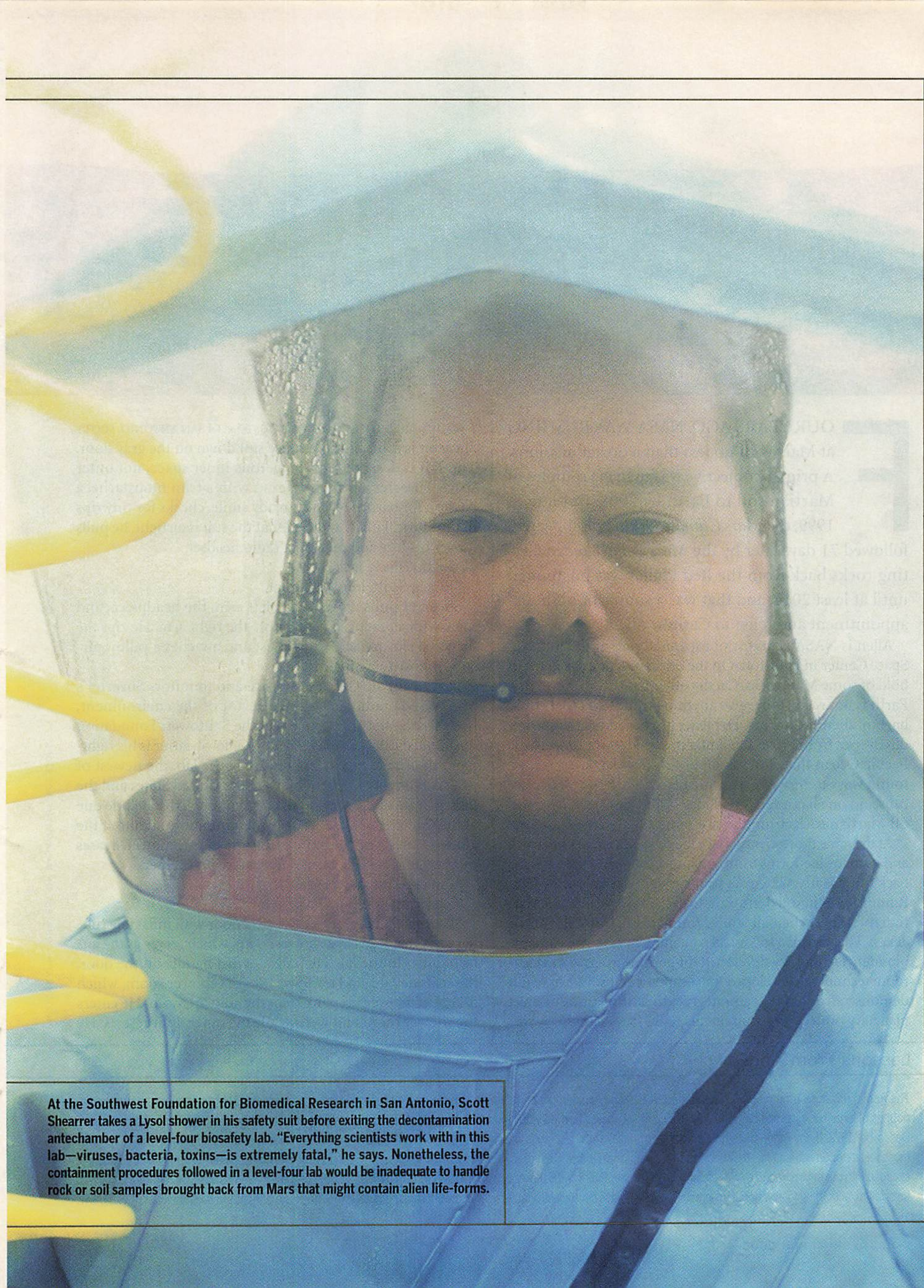
Until Dmanisi, there hasn't been a hominid dig that so captured the imagination since the excavations in the 1950s at Olduvai Gorge, a site on the edge of the Serengeti that yielded spectacular finds. "The combination of volume and quality will make [Dmanisi] the Olduvai Gorge of the 21st century," says Wood, who trained at the Rift Valley gorge under one of the field's towering figures, Richard Leakey.

The thought delights Lordkipanidze, who took up the reins at Dmanisi after his mentor, Leo Gabunia, died from cancer in 2001. "We have a chance to find bones you could never dream of," he says humbly. And they already have. ☒

Are We Ready For Alien Organisms?

In a dozen years, NASA plans to bring Mars soil samples to Earth. No one is quite certain what to do with them when they get here

By William Speed Weed ▼ Photography by Brent Humphreys



At the Southwest Foundation for Biomedical Research in San Antonio, Scott Shearrer takes a Lysol shower in his safety suit before exiting the decontamination antechamber of a level-four biosafety lab. "Everything scientists work with in this lab—viruses, bacteria, toxins—is extremely fatal," he says. Nonetheless, the containment procedures followed in a level-four lab would be inadequate to handle rock or soil samples brought back from Mars that might contain alien life-forms.

PHOTOGRAPH COURTESY OF NASA/*PATHFINDER*/JPL.

FOUR YEARS AGO, NASA WAS RUSHING at Mars with no less than a dozen missions. A primary objective was to bring samples of Martian soil to Earth by 2008. But late in 1999, the *Mars Climate Orbiter* disappeared, followed 71 days later by the *Mars Polar Lander*. Getting rocks back from the Red Planet was postponed until at least 2014, and that was a source of both disappointment and relief to Carlton Allen.

Allen is NASA's curator of astromaterials at the Johnson Space Center in Houston. On the one hand, he's dying to get hold of some Mars rocks. On the other hand, he believes that Earth is not ready to receive anything from Mars that could harbor alien life-forms. His fears are based partly on new discoveries from places like Antarctica and the bottom of the Pacific Ocean that show small life-forms like bacteria have found ways to thrive in extreme places. He also worries because no one has a very good idea of just how we might seal off Martian rocks from the rest of us.

At the same time, scientists face the challenge of keeping Earth and its many life-forms from contaminating whatever we bring back from Mars. As NASA's planetary protection officer John Rummel puts it, you don't want to declare you've found a Martian microbe "when all you've found is life from Florida or Texas." That means a successful containment lab must combine biosafety technology developed for germ warfare with clean-room technology developed for computer chips. "We have not demonstrated that we can integrate those functions to meet planetary protection requirements," Allen says bluntly.

TWO HUNDRED MILES WEST OF HOUSTON, IN SAN ANTONIO, SCOTT Shearrer lays his big blue space suit down on the gray floor. The suit is designed for dangerous inner space, not outer space. Shearrer, an affable Texan with a trim moustache, a passion for barbecue, and a ready smile, checks for tiny rips in the fabric. Finally satisfied that the suit is airtight, he pulls it over his legs and puts on a radio headset.

"Radio check, Jack."

"Roger, Scott, loud and clear."

Shearrer pulls on the suit's left arm, the headpiece, and then, with a practiced contortion, the right arm. He zips the diagonal closure across his chest and attaches a yellow air-supply hose to a hip port.

Jack Kelley sips tea in his office and monitors Shearrer's progress via radio. He is the director of the environment, health, and safety department at the Southwest Foundation for Biomedical Research in San Antonio. Shearrer is his right-hand man in charge of maintaining the lab, the newest of just six biosafety level-four labs in the United States and the only private one. Federal-government-run labs include one at the Centers for Disease Control in Atlanta and one at the United States Army Research Institute of Infectious Diseases in Maryland, a biological-warfare research center.

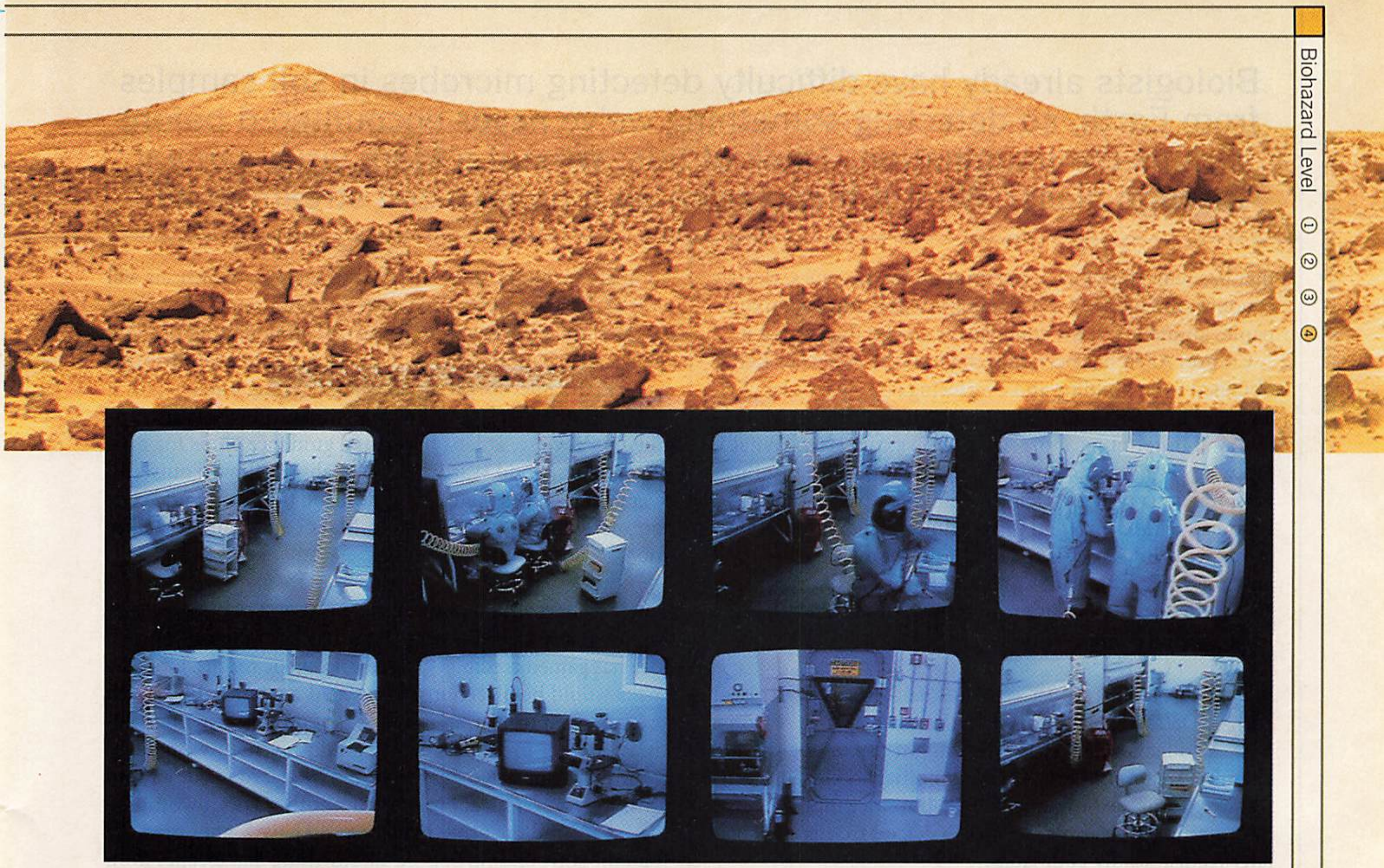
"I'm entering now, Jack."

"Roger, standing by."

Shearrer waits before a thick steel door with inflatable rubber seals that leads to a shower room, which serves as the antechamber to the lab. He pulls down a handle on the door, the seals deflate, and air flows into the shower room, which is kept at a lower pressure than the suit-up room. He enters the shower room and waits while the outer door reseals. He

Lessons From Apollo

The Apollo missions brought back a combined 842 pounds of lunar rock and soil between July 1969 and December 1972. If any moon bugs hitched a ride on those rocks—or on astronauts—they could easily have escaped into our environment. NASA's quarantine efforts failed, according to a National Research Council study on sample containment. The Lunar Receiving Lab was hurriedly built and underfunded. After completing the first moon landing in 1969, *Apollo 11* splashed down in the Pacific, scattering lunar dust. Moreover, beginning with the *Apollo 15* mission in 1971, NASA brass cut the astronauts' quarantine short for political reasons. "It was hard to take the rock quarantine seriously when these supposed vectors of disease were shaking hands in Houston supermarkets," says John Wood, the planetary scientist who chaired the Research Council study. In Wood's view, we're rather lucky that the moon appears not to harbor life. *—W.S.W.*



Top: Data collected on a plain where *Pathfinder* landed in 1997 suggest Mars may once have had a warm, wet climate similar to that of Earth about 3.8 billion years ago. Inset: A video monitor tracks level-four lab researchers F. Alex Hamill and Monica Avalos as they sit at a laminar flow cabinet and prepare a sample of deadly microbes and then examine the bugs under a microscope with a tabletop monitor display. Until they exit through a triangular-windowed door to a decontamination room, Hamill and Avalos remain tethered to air hoses, which maintain the pressure in their safety suits.

faces the inner door and deflates its seals. Again air flows in silently. Then Shearrer enters the hot zone.

If you ignore the man in the blue space suit, the hot zone is just a room with sinks, countertops, freezers, and microscopes. To the naked eye, it's as unimposing as a college biology lab. But labs like these are defined by how dangerous they are. A level-one lab contains relatively innocuous microbes, such as soil bacteria. A level-two lab is used to research microbes that are not normally airborne, such as those that cause hepatitis B, polio, and measles. A level-three lab is designed to contain potentially lethal airborne pathogens for which a cure is available, such as tuberculosis. Level four is for horror pathogens that can't possibly be seen with a naked eye but are lethal, incurable, and spread by air or blood-to-blood contact.

Take, for example, Guanarito, the virus that causes Venezuelan hemorrhagic fever. Virologist Rebeca Rico-Hesse has been studying it here at Southwest's lab. If Guanarito is not properly contained, Rico-Hesse and her colleagues will quickly develop headache, fever, joint pain, skin rash, nausea, and diarrhea. Before long they will bleed into their intestinal tracts, vomit, and defecate black digested blood. Within 10 days they could die from organ failure. "It's sort of 'all systems down,'" says Rico-Hesse.

After a routine maintenance check, Shearrer returns to the shower room. His suit could be crawling with any of several dozen nasty bugs that scientists study in this lab, so for a full five minutes he is blasted with Lysol. Once back in his khakis and polo shirt, it's off to Rudy's Barbecue—"the best barbecue on the planet"—with Jack Kelley.

Over creamed corn and brisket, Kelley tells how he encouraged the architects and engineers who built Southwest's lab to "think like a microbe." They designed a place where viruses can't get out the door, because the air always flows inward. They can't ride out on space suits, because the suits are sprayed with Lysol. They can't get through the air system, because of high-efficiency particulate air filters. They can't get out through the drains, because anything that does is combined with disinfectant and then cooked at 250 degrees Fahrenheit for two hours. The lab is an isolated concrete box

Biologists already have difficulty detecting microbes in soil samples from Earth, so detecting something we've never encountered before strains the imagination. Think of this: What if a Mars virus can eat through glass? What if it can swim up a pressurized stream of air?

that has only 18 points of penetration for air, pipes, electric conduits, and people. Each opening is sealed. Inspection companies annually test the concrete for cracks, then repair it.

Carlton Allen has been tapping into the expertise Kelley obtained from building and overseeing Southwest's lab. Kelley says he doesn't know whether there's any life on Mars to worry about, but he appreciates Allen's concerns. "What if I'm wrong?" he asks, pouring barbecue sauce. "In this business, you don't plan for what you think. You plan for the maximum credible event. And the maximum credible event here is that we bring back a bug that's resistant to everything and anything we've got. And it's a major hazard to the biosphere.

"So," he concludes, with rare gravity, "that facility has got to be the best we've ever built."

MODERN CONTAINMENT TECHNOLOGY WAS BORN AT FORT Detrick, Maryland, during World War II, in response to fears that Axis powers might use biological and chemical weapons. President Nixon officially closed the offensive part of the program in 1972, but since then scientists have labored to develop vaccines to defend troops and civilians against deadly pathogens.

"We were dealing there with highly infectious agents and lots of them," says Manuel Barbieto, a veteran of the program, whose job was to test and improve the containment systems. "Every time we had an accident [someone got infected], we would investigate how it happened and what we could do to correct the problem." Tests were run on the lab building to determine what kind of paint works best (epoxy), how to dispose of wastewater (cook it until everything in it is dead), and what the ideal material is for purifying the air (high-efficiency particulate air filters). They studied seals and air locks, disinfectants and lab tools. Perhaps the most important contribution by the researchers at Fort Detrick is the insistence that rooms in level-three and level-four labs, which contain lethal agents, must be at negative pressure compared with the outside, so that if there's a breach, air will flow in. Earth's viruses and bacteria cannot move from place to place actively. They must be carried around by air or fluid. They can't swim upstream. If air rushes into a lab through a crack, the microbes have no way of getting out.

The same principle of low-pressure airflow was also applied, in reverse, at labs that made guidance chips for missiles during World War II. In those labs, air flowed outward, keeping the atmosphere free of dust and bugs that could contaminate delicate assemblies. A Mars containment facility must be both at the same time.

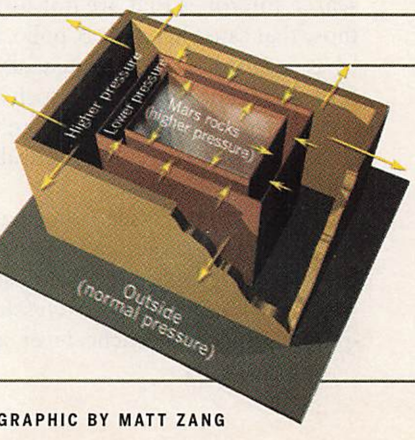
SCIENTISTS HAVE BEEN TRYING FOR DECADES TO FIGURE OUT HOW THEY can protect space rocks from us and us from them. Only one idea has gained credibility: three concentric rooms. First, the rocks would be placed inside a sealed container filled with pressurized nitrogen, an inert gas that prevents chemical activity. Higher pressure inside would prevent anything else from getting in. Then the box would be placed inside a room with lower pressure. Finally, yet another room would be placed around the other two. It would have higher pressure than the surrounding outside air. Anything that escapes from the innermost box would go into the lower pressure area of the surrounding box and be taken through a complex filter system. Any contaminants from the middle box that drift toward the innermost box would be unable to penetrate it. The concept is a high-tech version of a castle moat. Any dirty, science-ruining Earth germs would be prevented from reaching the castle. And any nasty Martian bugs inside the castle would be stopped cold if they tried to escape.

"It's a slam dunk!" Kelley says. "It just has to be souped up and adapted."

Allen isn't so certain. He is concerned about the points where the moat is breached by doors and glove holes that allow scientists to examine the rocks. He'd like to have a second solution to compete against the concept. He is working

A Box Within a Box Within a Box

The best proposal so far for containing life-forms within a soil sample from Mars is a system of three containment areas with varying pressures. The outermost area, or box, would be built like a computer-chip clean room with air at a slightly higher pressure than the outside atmospheric pressure. The area inside that box might be built like a biosafety level-four lab. It would have a lower air pressure than the room around it and filters that trap anything that leaks inward. The innermost box would contain the Mars soil sample and be pressurized with inert nitrogen kept at higher pressures than the surrounding box. A leak in the innermost box would cause nitrogen to rush out into the middle box. A leak in the outermost box also would cause air to rush outward, keeping earthly pathogens from entering and forcing any contamination toward the middle box, where it would be trapped.



GRAPHIC BY MATT ZANG

Because biosuits worn in a level-four lab must repel deadly microbes, researchers regularly douse the suits with soap and attach them to an air pump to check for leaks. The principle is similar to checking for holes in a tire; any micro-tears in the pressurized outer layer of the suit will cause the soap to bubble.

on a prototype clean box with a built-in robot that can cut open and analyze the rocks so people aren't directly involved.

John Rummel says he intends to quarantine any rocks brought back from Mars until they are proved safe. But a 2001 National Research Council report says biologists already have difficulty detecting microbes in soil samples from Earth, so detecting something we've never encountered before strains the imagination. "By far the most likely outcome of the preliminary examination of the Mars samples," the report states, will be a resounding "Uncertain." And think of this: What if a Mars bug can eat through glass? What if it can swim up a pressurized stream of air?

Ultimately, the arguments and the models become absurd. So veteran virologist C. J. Peters, the Ebola-hunting hero of Richard Preston's *The Hot Zone*, suggests building a type of containment that would be balanced toward attempting to keep the rocks sterile: "You have to make a big leap to say there's life on Mars, and another big leap to say we can find it, and another big leap to assume that we can do anything about it if there is." Of course, if we can't detect Mars life, we won't know how to sterilize it either.

To a planetary protection officer entrusted with keeping deadly life-forms out of Earth's biosphere, doing nothing is the one option that is completely unacceptable. "Within any undertaking, there cannot be 100 percent assurance," Rummel says, "but avoiding unacceptable risks is what I do, and minimization of the chance of planetary contamination is simple prudence." With the best solution still not obvious, both Rummel and Allen remain content with a single thought: We have 12 years to figure it out. ☒

Oh, deer

Exploding populations of white-tailed deer are stripping our forests of life

By Erik Ness Photograph by Geof Kern

Opposite: Should we just shoot 'em? Americans suffer from "sacred doe" syndrome, wildlife managers say. They protect deer from overharvesting even when deer populations are out of control.

MEMORIAL GROVE IS JUST NORTH OF STATE Highway 70 in Wisconsin. It's dedicated to four local Forest Service employees who didn't return from the Second World War, but it's also a living memorial to the great trees that once towered over the lake country. By accident or luck, 47 acres here were never cut, and the eldest hemlock checks in at a hoary 320 years. On a gray January morning, Tom Rooney tramps about on a thin crust of snow, surveying the forest floor. "Lots of maple seedlings," he says, "but there are hardly any hemlock."

As a postdoctoral botanist with the University of Wisconsin, Rooney has studied hemlock regeneration at more than 100 sites. "We lost a lot of hemlock during the wave of logging," he says, referring to the Paul Bunyan era at the turn of the last century. "Now we're losing the remaining ones to browsing." He singles out a small maple as thick as a soda straw and less than two feet tall. All about the stem, shoots have been clipped off, their growth redirected by precise dentition—bites. "We don't know what the browsing is like, but the plants sure know."

When a tree begins to die, it can take years before anyone notices; forests can hide their decline for decades. Seeds fail, saplings wither, young trees don't make the vault to the canopy. Eventually the last survivor from a once-mighty stand reaches the end and casts a final seed. Standing before a hemlock seedling about three feet tall, Rooney parses its branches with gloved hands. "A lot of the lower branches appear to be browse-damaged," he says. "You have needles coming off the main stem, which indicates the plant is stressed, so it is getting eaten periodically." The usual suspects: deer.

Fifty years ago, botanist John T. Curtis of the University of Wisconsin orchestrated a massive reconnaissance of the state's plant communities. He then put it all together in a book, *The Vegetation of Wisconsin,* which established a benchmark. In 2000 and 2001, Rooney and his boss, botanist Don Waller, revisited 67 of Curtis's northern plots. Of the 62 sites still undeveloped, the most changed were in two state parks where deer hunting is not permitted: Lake Gogebic in Michigan and Brunet Island in Wisconsin. Both lost 75 percent of their species between 1950 and 2000, and sites across the board showed dramatic declines. On average, Waller and his team found almost 20 percent fewer species than Curtis had 50 years before, although they sampled the same sites much more intensively.

"People have heard of endangered species. They haven't thought that their local woodlot may have only half the species that it had 50 years ago," Waller says. "We have around us today plant communities that still look intact, that still seem intact. The trees are still standing; they still have some flowers underneath them in the springtime. But those grand-canopy trees may not be reproducing. This is the leading edge of the wedge; it's what happens before things go extinct."

PHOTOGRAPH BY STEVE APPS/WISCONSIN STATE JOURNAL.

DEER KILLED in Wisconsin's Blue Mound State Park are tested for chronic wasting disease, a neurological disorder related to mad cow disease. Plague and overpopulation often go hand in hand. Michigan deer have been beset by bovine tuberculosis, and southern deer suffer from a hemorrhagic virus. Chronic wasting disease was once found only in western deer and elk. Then, last February, the disease somehow leaped 700 miles to southern Wisconsin. The state is eradicating deer within 10 miles of the epicenter of the outbreak, plus half the deer in the surrounding counties. Biologists doubt the plan will succeed.

> 'Just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer'

The solution, botanists say, is as obvious as it is politically explosive: Americans need to kill more deer.

THE STORY OF DEER IN AMERICA HAS BEEN A TRAGEDY OF BOTH GOOD and bad intentions. In 1607, when settlers landed at Jamestown to start the first British colony, there were between 24 million and 31 million white-tailed deer in North America. Those numbers began to decline as settlers pushed west, and the bottom fell out in the late 1800s. Hunters slaughtered deer for their meat and hide just as they did buffalo, and with similar results. The most industrious hunters routinely bagged 150 to 200 deer in a season; one Virginian killed 2,700 in his career. By the end of the century, less than half a million deer were left. In vast tracts of the country—Massachusetts, New Jersey, southern Wisconsin, Pennsylvania—there were almost no deer at all.

What happened next was a textbook case of overcompensation. In 1896 the U.S. Supreme Court declared all wild animals property of the state, forcing hunters to obtain licenses and abide by hunting restrictions. Conservationists such as Theodore Roosevelt had already begun to lay some ethical ground rules. They declared it unsporting to trap large game animals or to shoot them while they were crossing streams or snowbanks. They urged hunters to spare does and fawns and concentrate on bucks. Soon, state game commissions were formed, funded by taxes on firearms and ammunition, and hunting seasons, bag limits, and sex restrictions helped deer populations recover. By the 1940s, 30 states had *too many* deer. In northern Wisconsin, deer populations had grown so large that some were starving to death.

The situation seemed tailor-made for Aldo Leopold. Both a pioneering conservationist and a clear-eyed pragmatist, Leopold had more or less invented the field of wildlife management with his 1933 book, *Game Management*. Leopold lived on a washed-up farm along the Wisconsin River and set up the nation's first wildlife ecology program, at the University of Wisconsin. In 1943 he took control of the Wisconsin Conservation Commission and tackled the deer problem head-on.

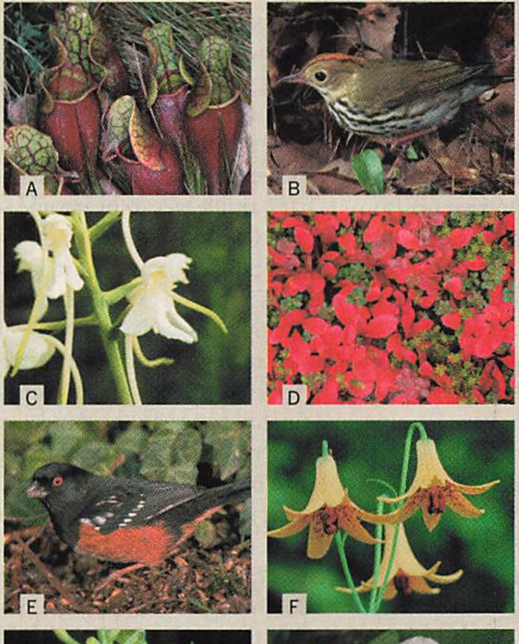
Instead of feeding deer and killing wolves, Leopold argued, people should focus on killing does to decrease the overall population. "Just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer," he wrote.

Leopold's views helped set the stage for scientific herd management, whereby hunters register the sex and age of each kill, and biologists use simple models to reconstruct the size of the herd. By looking at the relative growth rates of the herd, biologists can now deduce a given area's carrying capacity—how many deer it can support without endangering other inhabitants. Although Leopold was well known and respected, his point of view was anathema to hunters. For decades they had been taught to think of deer as a precious, endangered resource. One fruitless hunt was enough to convince them that nothing had changed.

Today Wisconsin boasts 1.6 million deer, 700,000 licensed hunters, and a deer-management system that is tops in its field. Yet biologists who think there are too many deer are still excoriated by hunters and nonhunters. When the number of antlerless deer killed dropped 42 percent in 2001, hunters didn't blame the unseasonably warm weather, which allowed deer to hunker down and evade tracking. They blamed state game managers for encouraging the shooting of too many does. "Most hunters have never experienced a sustained decline in deer populations," says Keith McCaffery, a retired deer biologist who volunteers for the state of Wisconsin. "It's almost like a record number every year." Seeing deer in the forest used to be a magical experience, McCaffery says. Now it's exciting only if they're coming through your windshield. ↘

COLLATERAL DAMAGE

In some forests, ravenous deer have killed off as many as 50 percent of local plant species. As flowering plants disappear, the animals that depend on them also suffer. A few of the victims:



A. Purple pitcher plant. B. Ovenbird. C. White fringeless orchid. D. Red bearberry. E. Eastern towhee. F. Canada lily. G. Loesel's twayblade. H. White large-flowered trillium.

PHOTOGRAPHS: A. FRANK LANE PICTURE AGENCY/CORBIS; B. JOE McDONALD/CORBIS; C. HAL HORWITZ/CORBIS; D. DARRELL GULIN/CORBIS; E. TIM ZUROWSKI/CORBIS; F. JIM ZIPP/PHOTO RESEARCHERS; G. HAL HORWITZ/CORBIS; H. HAL HORWITZ/CORBIS.

'Seeing deer in the forest used to be a magical experience. Now

A FEW MILES WEST AND SOUTH OF MEMORIAL GROVE IS FOULD'S CREEK, home to another large hemlock grove bordered by a wetland. Deer like to gather under hemlock in the winter because the flat boughs catch the snow, uncovering browse and leaving a clear escape path from predators. Such "deer yards," as these gathering points are called, are often hit hardest by browsing. Sometime in the 1930s, when Wisconsin's deer problems began, a protective fence was erected around a corner of the yard, and it has been maintained ever since. It's not worth much scientifically—there are no records and no controls, and a forest without deer is as unnatural as one with too many—but Rooney sees a lesson in the contrast.

"This is our alternate trajectory: No deer for the last 60 years," Rooney says as he scales the rotting ladder. The contrast is striking: Outside the fence, the understory is wide open, roomy enough to park a Winnebago. Inside, you have to crouch and crawl to move about. Clearly, the persistent nibbling of generations of deer is a tremendous force. Inside the fence, the hemlock is reproducing; a stand of hemlock can persist for 3,000 years or more. Outside, the last stands are dying out. "We don't have any midsize hemlock here because of what happened 50 years ago," Rooney says. "We don't have any hemlock coming in now because of what's happening today."

You can learn a lot about the effects of browsing by examining what deer most like to eat. Rooney finds a good example inside the fence: three young white cedars. The cedar's common name, arborvitae, which means "tree of life," dates from the 16th century, when French explorer Jacques Cartier and his men brewed tea from its bark and leaves to overcome scurvy. Cedar is loaded with vitamin C, and it's easier to digest than other winter browse. If a deer can get enough of it, it may not even lose weight in the winter. Yet that very wholesomeness limits its supply. In the Wisconsin uplands, cedar has been browsed nearly to eradication. Canadian yew is tasty as well, and also quite scarce. Moving down the chain of palatability comes hemlock, balsam fir, pine, and finally spruce. In most of Wisconsin deer have already arrested the regeneration of cedar, yew, and hemlock. Now they appear to be showing some interest in fir. Bite by bite, they're eliminating their own favored food sources.

This is how herbivores structure a landscape. In areas with lots of deer, grasses survive because they contain silica, which wears down teeth. They also propagate with tiny seeds, or underground, and grow so low that they rarely get clipped in passing. Ferns do well because they've evolved nasty, unpalatable chemicals in their fronds. But flowers are another story. They invest tremendous energy in their spring emergence but pay the price if winter doesn't knock back the deer herd.

A few years back, in the forest of northwestern Pennsylvania, Tom Rooney came upon some large boulders and decided to scale one. Once on top, he was astonished to find a lush little garden growing on the rock. Good science is opportunistic, and Rooney realized he had come upon a natural experiment. Like the fence at Fould's Creek, the boulders were exclosures, keeping plants out of reach of the deer.

Rooney spent the afternoon counting, measuring, and identifying plants on 34 boulders from eight to 50 feet tall and 34 shorter boulders low enough for deer to reach. When he was done and had added up the numbers, he found that plants on the tall boulders grew three times as densely as those on the short boulders. They were 30 percent larger and nearly 40 times more likely to flower. What stuck with him most was the sight of an elegant lily with tiny, bell-shaped magenta flowers that grew on one of the boulders. Down on the forest floor, the lilies were scrawny and barren, but this one had grown to full size and flower. In the absence of deer, the forest had bloomed.

BY ONE COUNT, 98 SPECIES OF THREATENED AND ENDANGERED PLANTS, many of them orchids and lilies, are disturbed by deer browsing. While few if any species will be driven to extinction by browsing alone, the cumulative effect across the landscape can be startling. In a single park in Columbus, Ohio, a deer herd eradicated more than 150 plant species.

It doesn't stop there: When plant populations get hammered, the effect ricochets up the food chain. Across the Appalachian divide from Fould's Creek, biologist Bill McShea has spent the past 14 years studying the forest at the Smithsonian Institution's Conservation and Research Center in Front Royal, Virginia. Like many scientists who deal with the effects of deer, he didn't plan it that way. He was hired to study small mammals but soon found there weren't many around. There were deer, though, plenty of them.

McShea began to think there was a connection, and he found it in the Kentucky warbler. This little songbird likes the gaps in a mature forest, where a tree has fallen and the light draws a crowd of plants. It nests close to the ground, so it needs foliage—such as raspberry and blackberry patches—to hide in and hunt insects from. But when deer populations get too high, the warbler gets pushed out. Beginning in 1979, when all deer hunting was stopped at Front Royal, McShea and his colleagues watched for 13 years as the warbler disappeared from four of five habitat zones on the reserve. Nationwide, the same tale has been repeated again and again: As deer populations have exploded over the past 40 years, Kentucky warbler populations have declined by 1 percent per year.

Too many deer simplify a forest, McShea says. "Instead of ending up with woody seedlings and herbaceous plants and birds and insects, all that productivity ends up inside the deer." Other examples abound: In England, when deer were kept out of one study site, moth populations quadrupled. In Finland and Sweden, slug and snail populations took off when moose and reindeer were kept out of forest plots. In the northeastern United States, deer have triggered a chain reaction by gobbling up the acorns on which deer mice depend. The mice usually keep gypsy moth populations in check by eating the moths' pupae. But when the acorns disappear, mouse populations go bust—and gypsy moth populations boom.

A simplified landscape isn't necessarily unattractive. A well-grazed forest of mature trees that has an airy understory of ferns is often called a fern park. It's homogeneous—white bread with mayonnaise—but it's pretty to walk through. "A

PHOTOGRAPH BY ALLEN RUTBERG/HSUS.

world with high deer density does function, but it doesn't have a lot of the qualities that we want in a protected area," McShea says. Environmentalists tend to focus on saving individual plants or animals, he says. They'd get a lot further by just managing the deer: "They run the show right now."

MCSHEA'S SUGGESTION SOUNDS REASONABLE. BUT "MANAGEMENT" IS mostly a tidy euphemism for hunting and killing, and that's where the trouble starts. Hunters want as many deer as possible, to improve the chances of a kill. Many nonhunters would rather not kill any deer at all. Either way, wildlife managers can only protect the forest by battling public opinion.

After the poor hunt last fall, Wisconsin game manager Bill Mytton spent weeks fielding calls from angry hunters. "I have not received one phone call from anybody saying, 'Good job! Looks like deer numbers are down. Looks like orchids are going to live longer,' " he says. Even the head of the Wisconsin Conservation Congress has complained that "more deer are certainly tolerable and acceptable."

Animal rights groups, for their part, want deer controlled humanely. Yet alternatives to hunting have had limited success. Relocating deer just puts the problem in somebody else's backyard, and the animals often suffer from the stress of capture, transport, and unfamiliar digs. Contraception can help control isolated populations, but it costs a great deal, and deer are too short lived, mobile, and fertile to be affected for long.

Recreational hunting is simply the best tool for the job, biologists agree. But getting hunters to live with fewer deer requires a radical change in attitude, and the only way to achieve it is not through technology but through old-fashioned education and conversation. As Aldo Leopold put it, "A Commission must drag its public along behind it like a balky mule, but with this difference: the public, unlike the mule, kicks both fore and aft."

Over the past three winters, the Pennsylvania Game Commission has held some 200 public meetings to discuss deer populations, and the people have come. They have filled high school auditoriums and spilled into the cafeterias. They have listened to game managers and given them a piece of their minds. Last year, around 35,000 attendees received a video that explained the radically restructured deer season. "This a keystone issue," says Gary Alt, the biologist who's leading the educational offensive. "This animal decides what will live and die in a forest."

Hunters need to learn to look at the forest the way a rancher looks at his pastures, Alt says. "He doesn't go out and do a $400,000 study to figure out when to move the cows. He just glimpses the pasture and says, 'This grass is getting chewed up.' " Whether the natural history lesson will sink in remains to be seen, but Alt knows there's no alternative to teaching it. "It's not just an endeavor in science," he says. "It's an endeavor in bringing a society together." ☒

On Fire Island National Seashore in New York, deer feed on specially placed corn. Such contained feeding lures deer to sites where they can be shot with darts that contain contraceptives.

REviews

Empire of Blood

To the Aztecs, a good death was a violent death

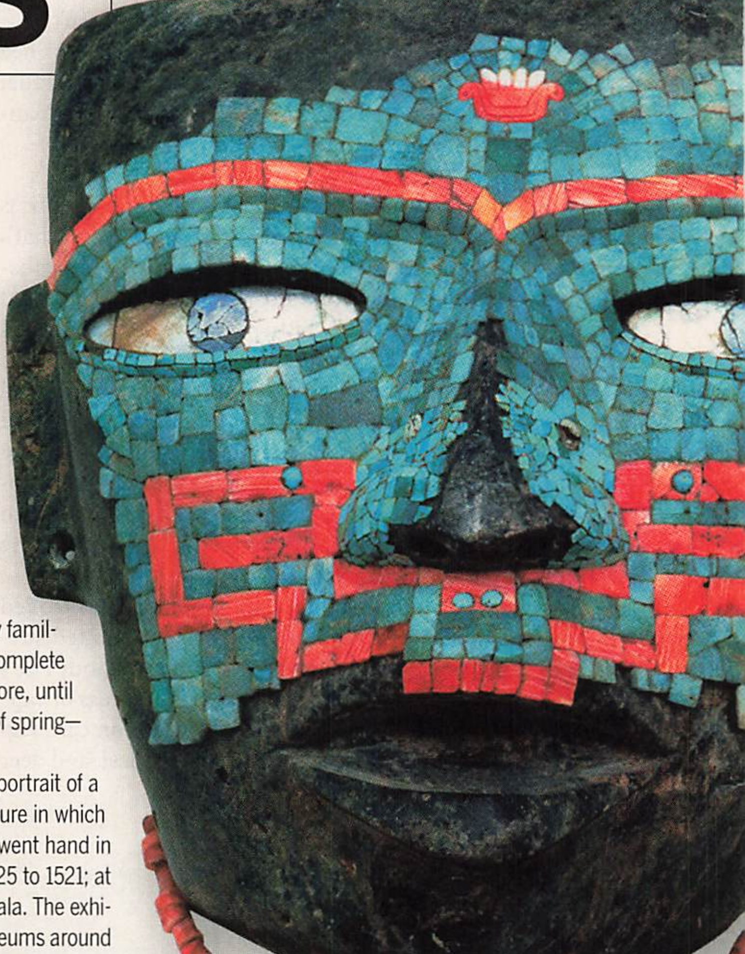
By Alan Burdick

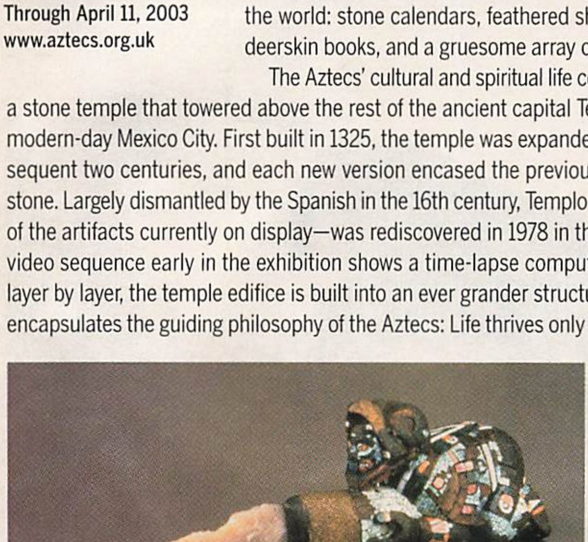
OF THE 350 ARTIFACTS OF AZTEC CULTURE NOW ON DISPLAY AT THE ROYAL Academy of Arts in London, the most discomfiting is a two-foot-tall clay statuette of Xipe Totec, the ancient Aztec god of spring. The name translates as "our flayed lord," and the sculpture depicts him dressed in an oddly bobbled tunic—the clay facsimile, it turns out, of a human skin turned inside out. The bobbles represent the globules of fat that lie beneath human skin, a phenomenon that, as the surrounding exhibit makes unflinchingly clear, was entirely familiar to Aztec artists. For certain rituals, Aztec priests donned flayed human skins, complete with the victim's scalp and face, and continued to wear them for 20 days or more, until the rotting garment fell away. Thus new life sprang from the old, and the return of spring—for everyone except one unfortunate soul—was insured.

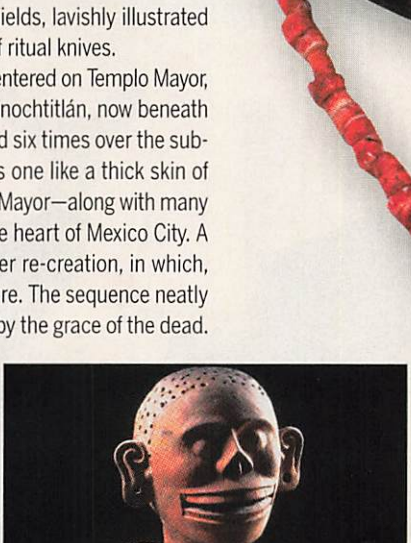
The most comprehensive Aztec exhibition ever mounted provides a riveting portrait of a society obsessed with the natural cycle of life and death—a fiercely refined culture in which nobility and war, scholarship and human sacrifice went hand in severed hand. The Aztec empire flourished from 1325 to 1521; at its peak it stretched from central Mexico to Guatemala. The exhibition includes objects and artwork culled from museums around the world: stone calendars, feathered shields, lavishly illustrated deerskin books, and a gruesome array of ritual knives.

Aztecs
The Royal Academy of Arts, London
Through April 11, 2003
www.aztecs.org.uk

The Aztecs' cultural and spiritual life centered on Templo Mayor, a stone temple that towered above the rest of the ancient capital Tenochtitlán, now beneath modern-day Mexico City. First built in 1325, the temple was expanded six times over the subsequent two centuries, and each new version encased the previous one like a thick skin of stone. Largely dismantled by the Spanish in the 16th century, Templo Mayor—along with many of the artifacts currently on display—was rediscovered in 1978 in the heart of Mexico City. A video sequence early in the exhibition shows a time-lapse computer re-creation, in which, layer by layer, the temple edifice is built into an ever grander structure. The sequence neatly encapsulates the guiding philosophy of the Aztecs: Life thrives only by the grace of the dead.







The fifth-century burial mask and necklace (above) is from Teotihuacán, a pre-Aztec city that a millennium later attracted Aztec pilgrims. A flint knife (far left) is typical of Aztec artifacts used for human sacrifices. Similar knives were found near a temple housing the life-size 15th-century statue of the Lord of Death (left).

As the Aztecs well knew, theirs was not the first culture to inhabit the region. The Olmecs, Maya, and Toltecs had all come and gone by A.D. 700. Some of what modern scholars know about those cultures stems from the Aztecs' own fascination with those who came before them. They visited and excavated the ruined cities of their predecessors and assimilated the old gods, calendars, writing, and crafts.

From borrowed beginnings the Aztecs invented a rich culture of their own. Hand-painted pictographic manuscripts, or codices, of which several exquisite examples are on exhibit, offer modern scholars a window into daily Aztec life. A complex, two-calendar system enabled the Aztecs to track seasons and crop schedules. And a variety of intricately carved animal sculptures—lizards, serpents, eagles, even an oversize stone carving of a flea, with careful attention given to its bloodsucking mouth parts—attest both to the Aztecs' skills as artisans and their abiding interest in the natural world. Being the center of the universe (as they saw themselves), the Aztecs felt obliged to monitor its rhythms and contents, lest the whole thing fall apart.

Human sacrifice was integral to this cosmic upkeep. The gods had killed, flayed, dismembered, or otherwise disembodied themselves to create the Aztecs' world, and the Aztecs apparently felt obligated to repay the debt in kind. Hence the finely ornamented flint knives that were used to cut open the breastbones of living victims; hence the admirable skill devoted to creating clay and stone urns to hold drained blood and vital organs. The voice on the exhibition audio guide assures the listener that, to the Aztecs, "a good death was a violent death." Standing amid such articles of pain, however, one wonders how widely this view was shared. The caption beneath a statuette of a hunchbacked man dryly notes that deformed individuals were cared for by the Aztec state "until a solar eclipse took place, at which point they were the first to be sacrificed."

With the occasional exception of the physically handicapped, most sacrificial victims were captives of war. Indeed, Aztec warfare was highly ritualized, its sole purpose not to kill opponents but to capture them. Warriors entered battle adorned in feathers, jewels, and jingling bells. Fearsome as they were in this specialized activity, the Aztecs were no match for Spanish soldiers, who marched on the city in 1521 intent on killing and conquering, not taking captives. An illustration from the Codex Azcatitlán shows a column of armored horsemen advancing on a group of Aztecs, nattily attired in eagle costumes, with the ease of tanks crossing a field of flowering teasels. After 93 days of siege and starvation, the Aztec empire, so fully committed to the worship of death and regeneration, found itself on the losing end of the equation. The transition to Christianity, the largest mass conversion in history, was soon under way.

Even in defeat the Aztec spirit continued to thrive. Small shrines to the ancient gods appeared in the region well into the 19th century. One of the most beautiful artifacts in the exhibit is a portrait of the Mass of St. Gregory, dating from 1539, rendered entirely in Aztec style with small blue feathers. As for Templo Mayor, it was flayed by the Spanish, its skins of stone removed and recycled in the founding of Mexico City. And there they remain: underfoot, bearing the weight of the living.

POETRY

IN EVERY STEELY, COLD, RATIONAL SCIENCE MAVEN'S heart runs a red-hot stream of romance. Finding the stream and allowing yourself to get in touch with it is what's difficult. To the rescue comes the always iconoclastic Diane Ackerman, author of *A Natural History of the Senses*. (And let's stop for a moment to discuss priorities: If you haven't read *that* book, put down this review and run for the nearest library.)

Ackerman's lovely little book of poetry will appear at first glance to be a good gift for a child, and indeed a child would be handy to have around so you could justify reading the book aloud. It is more than that, though. It is a book for the curious child in each of us, and lots and lots of the clever wordplay is as much to an adult's liking as the words in Dr. Seuss's *Cat in the Hat*. There is also a lot of learning to be had here (I suspect she couldn't help herself). Try this—aloud, please—for a tickle of an example.

Swans are not white—they're clear.
The same is true of polar bears.
And blue jays are certainly not blue,
but also clear. Perhaps you knew.
In nature, colors aren't what they appear,
but subtle and tricky, and ever so quaint.
So, animal colors are rarely like paint.
Tiny air bubbles inside swan feathers
trap all the colors, splash them together,
and abracadabra! We think we see white there,
but as I said, swans are actually clear.
The same is true of polar bears.
And blue jays are certainly not blue,
but also clear. Perhaps you knew.

Don't make the mistake of reading it once. Read it at least three times. Then you'll understand why a scientist like Carl Sagan was crazy about this woman.

—*Stephen L. Petranek*

Animal Sense

By Diane Ackerman,
illustrated by
Peter Sís
Alfred A. Knopf, $14.95

PHOTOGRAPHS: CLOCKWISE FROM TOP, COURTESY OF MICHAEL ZABE; COURTESY OF MICHAEL ZABE; COURTESY OF THE BRITISH MUSEUM, LONDON.

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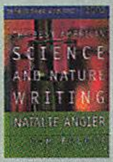
2. **THE DEMON IN THE FREEZER: A True Story**
By Richard Preston, Random House

3. **$E = mc^2$: The Great Ideas That Shaped the World**
By Pete Moore, Friedman/Fairfax

4. **THE BLANK SLATE: The Modern Denial of Human Nature**
By Steven Pinker, Viking

5. **THE UNIVERSE IN A NUTSHELL**
By Stephen Hawking, Bantam

6. **THE BEST AMERICAN SCIENCE & NATURE WRITING 2002**
Edited by Natalie Angier and Tim Folger, Houghton Mifflin



This superb anthology includes several *Discover* contributors.

7. **ON THE SHOULDERS OF GIANTS: The Great Works of Physics and Astronomy**
Edited by Stephen Hawking, Running Press

8. **HEAVEN & EARTH: Unseen by the Naked Eye**
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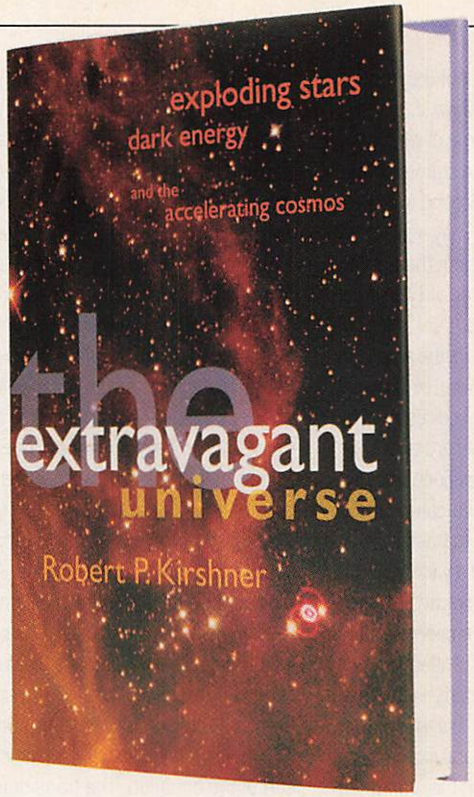
By Ken Alder, Free Press

Source: Barnes & Noble Booksellers



Cosmic Surprise

Something wild is loose in the universe

By Laurence Marschall

IN 1917 ALBERT EINSTEIN UNCOVERED EVIDENCE OF A powerful cosmic force that no one had previously suspected. Astronomers and physicists had long assumed that remote stars and galaxies drifted around at random, like dust motes in a sunbeam, while the universe itself remained static. Yet young Einstein's equations indicated that, without a force to counterbalance gravitation, the natural attraction of everything in the universe to everything else would set the universe into some sort of systematic motion—either contraction or an ever-slowing expansion. So he added a term to his relativistic equations to represent the compensating force that would keep the universe still: a "cosmological constant." From the outset, he hated it, because it seemed to be just a mathematical gimmick, an ad hoc quantity tied to no known property of matter. A dozen years later, when new observations by Edwin Hubble and Vesto Slipher revealed that the universe was *not* static but expanding, Einstein was only too glad to kiss the cosmological constant good-bye, with some regarding it as his greatest blunder.

Then again, it might be his greatest prediction. In the last decade, two independent and sometimes competitive research groups have used some of the most luminous objects in the universe—exploding stars dubbed Type Ia supernovas—to gauge the distances and motions of galaxies with unprecedented precision. They've found that the universe is not only expanding but also that its expansion is speeding up, a discovery one wouldn't expect if only gravity were at work. Something is repelling the galaxies, something that astronomers are now calling dark energy—something that looks just like the long-discarded cosmological constant.

Harvard astronomer Robert Kirshner is a charter member of one of the two groups that made the cosmological constant respectable again (the other group is led by Saul Perlmutter at the Lawrence Berkeley National Laboratory in California). Kirshner, an expert on supernovas, has taught or collaborated with most of the leading figures in the revisionist cosmology. Fellow astronomers—and generations of Harvard undergraduates—have also long appreciated him as a raconteur of exceptional eloquence, so it is hard to imagine anyone better suited to give us the inside story on the new discoveries.

The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos

By Robert P. Kirshner

Princeton University Press, $29.95

Kirshner does not disappoint. He tells, in large part, a story of how improved technology has enabled astronomers to look farther into the distance and thus further into the past. In our cosmic neighborhood—extending to even hundreds of millions of light-years—it's impossible to distinguish between a universe that slows down and one that speeds up. Only when we look at galaxies billions of light-years away, collecting the light they emitted billions of years ago, can we see that the most distant galaxies are moving more slowly than we would expect from observations of nearby galaxies, an indication that the universe has since sped up.

Even with that new data, however, Kirshner and his fellow scientists, supposedly the most dispassionate of observers, had to struggle to loosen the hold of old prejudices. Einstein and the generations who followed him regarded the cosmological constant as the addition of something unnecessary: The universe, by contrast, is *supposed* to conform to the simplest, most economical rules of design. (Scientists even have a name for this: Occam's razor, after the medieval philosopher who proposed that the simplest answer to a problem is usually best.) When a reporter asked Brian Schmidt, one of Kirshner's former thesis students who led the supernova search, what he thought about his unexpected results, he replied, "My own reaction is somewhere between amazement and horror."

The lesson of Kirshner's story is that we should be delighted, not horrified, at the new picture of the universe that is emerging. In the end, nature calls the shots, regardless of the preferences of Albert Einstein, William of Occam, or the collective membership of the American Astronomical Society. Nature can be simple, but just as often nature is extravagant (consider for a moment the giant squid, the human brain, or the weather). As Kirshner so elegantly puts it, "The universe is wilder than we ordinarily dare to imagine."

TOYS

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THE ROOMBA FLOORVAC, A squat disk about 12 inches in diameter, scuttles across the carpet like some Precambrian pet, ingesting crumbs and dirt as it navigates walls, circles chair legs, and crisscrosses the room. Roomba operates autonomously, leaves the carpet remarkably clean, and when the job is done, stops and shuts itself off.

The robotic vacuum cleaner is not a new idea, but Roomba is the first commercially available model that's truly affordable—and simple. There's no programming; you just turn it on and let it go. A bump sensor tells the machine when it has reached an obstacle, and infrared sensors guide it along walls and prevent it from tumbling down stairs. If the Roomba gets stuck on a household object, it automatically switches off—then beeps for help.

Although the Roomba uses only 30 watts to do its job—a typical vacuum uses 1,000 watts—its actual air velocity at carpet level is comparable to a conventional vacuum cleaner's. One drawback, however, is its small dirt capacity: The particle bin and dust filter must be emptied after each use. Still, the Roomba serves as an efficient and genial ambassador for robot-kind. That's good news for its manufacturer, iRobot, which is hard at work developing other robots for everyday use.

—Fenella Saunders

PHOTOGRAPHS: TOP, JENS MORTENSEN; BOTTOM, COURTESY OF iROBOT.

ADVERTISEMENT

The Counterfeit Principles of Self

Socrates is purported to have said that the unexamined life is not worth living, but he failed to tell how to conduct that examination. This treatise fills that need. Socrates also said, "Think not those faithful who praise thy words and actions, but those who kindly reprove thy faults."

Therefore, first, we shall kindly reprove disparaging persons of their fault of failing to act on information developed by the late Richard W. Wetherill nearly eighty years ago. He identified the basic principles of nature's law of social behavior. They are the inviolable, self-enforcing principles unique to all natural laws: ***Right action gets right results; wrong action gets wrong results.***

Wetherill had coined the word *humanetics* to identify his study, but nature's social law is presented here as the law of rational behavior. It defines rationality as action that is inclusively ***logical*** because it works, ***appropriate*** to the situation, and ***moral*** because it is true to the facts.

Richard W. Wetherill
1906-1989

Ordinarily people behave as if they had multiple options. Natural law indicates two: what is right or what is wrong. In computer lingo, action is on or off, 1 or 0.

Wetherill taught, "There are principles people reason from that determine their behavior, and among them are counterfeits. Some people object to the use of the term "counterfeit" principles, but consider counterfeit money. It is not real yet when accepted, it assumes a kind of reality. In that sense, there are counterfeit principles that people form, causing irrational behavior.

What follows are five points describing counterfeit principles. Their study and application enable people to examine their lives in a way that makes their lives truly worth living.

1. What are counterfeit principles? They are the commands to self that people form such as "My mind is made up, and nothing anyone says will change it."
2. How are counterfeit principles formed? While emotionally upset, people form unrealistic thoughts that get lodged in memory for repeated use such as "When I feel attacked, I fight back. "
3. What do counterfeit principles cause? They cause attitudes, leading to behavior that is out of touch with reality such as "Nobody is going to tell me what to do."
4. How are counterfeit principles rescinded? When the concepts are consciously recognized as false, they drop from memory and no longer influence behavior—just as nobody continues to act on exposed lies.
5. What results? Thinking clears on topics formerly distorted by counterfeit principles. Rationality is gained, making life truly worth living.

Merely observing people's behavior confirms the validity of nature's social law. Frequently they mention their counterfeit principles such as "If I don't like it, I won't do it." It is widely known now that lifestyles impact people's health. Medical reports state that unhealthy foods, bad habits, and stress cause illness. Next, consider the millennia it has taken to establish that connection. But people still continue their destructive behavior, not knowing that counterfeit principles are causing it. This treatise briefly outlines the formula that when universally applied will stem the tide of humanity's pandemic irrationality.

To paraphrase Socrates: Think not those faithful who praise thy words and actions, but those who kindly reprove thee of thy counterfeit principles. Rescinding counterfeit principles produces rationality, and adapting behavior to nature's social law enables *the law* to bring about peace to those who conform.

For further information, call 1 800 992-9124 to request a no-obligation, free mailing or write to The Alpha Publishing House, 1101 Enterprise Dr., PO Box 255, Royersford, PA 19468. Our Website www.alphapub.com displays articles and Wetherill's book Tower of Babel (out of print) along with descriptions of the six other books that are available, explaining nature's law of rational behavior.

Text written by E. Marie Bothe, President of The Alpha Publishing House and former assistant to Mr. Wetherill for thirty years.

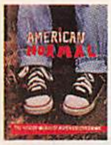
Who's Crazy Now?

Even the merely eccentric may get labeled mentally ill

By William Speed Weed

American Normal: The Hidden World of Asperger Syndrome

By Lawrence Osborne
Copernicus Books,
$27.50



GEORGES HUARD MEASURES TIME PRECISELY IN SECONDS. HE'LL SAY, "I was born one billion three hundred thousand seconds ago." Huard's obsession with time is so overwhelming that he goes to sleep every night to the beep of an alarm clock that goes off every 10 minutes. There's no one else in bed to be bothered by the incessant beeping, because Huard, 41, is not likely to have intimate relationships. He is autistic, and many of his symptoms are classic: obsession with mathematics and time, a total lack of ability in matters social.

But Huard has Asperger syndrome, a subset of autism less debilitating than other forms. Indeed, many people with Asperger's have remarkably productive lives: Temple Grandin, profiled by Oliver Sacks in *An Anthropologist on Mars,* is a leading expert in the design of slaughterhouses. Huard is a computer programmer at the University of Montreal.

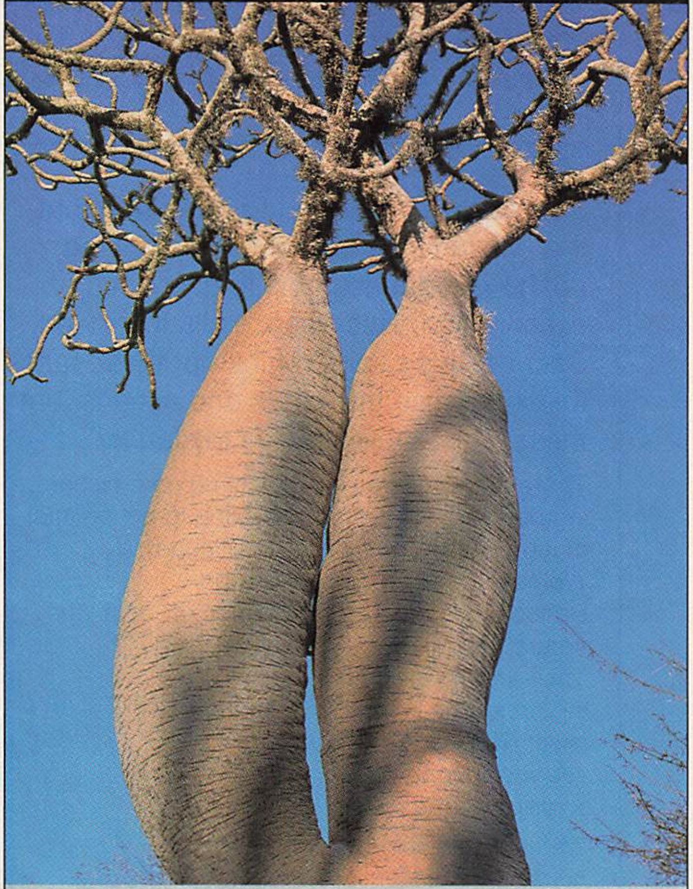
Author Lawrence Osborne plunges into the world of Asperger's on "a metaphysical quest" to discover the meaning of "abnormal" and whether it really applies to people with Asperger's. It's something of a skittish quest, with Osborne writing in different modes from section to section. He adopts a glib reportorial tone in profiling various "high functioning" individuals with Asperger's, such as Glenn Gould, the celebrated pianist. Other times, he indulges in strangely confessional reveries—for instance, wondering if his obsession with airport layouts might be a symptom of Asperger's. Elsewhere, Osborne makes broad judgments about what he sees as the absurdity of many mental health classifications.

To Osborne, people like Georges Huard are merely eccentric. His life is focused differently from other people's, but so what? He's a happy, independent person. His obsession with time is wonderful for him. "It gives me my most fundamental pleasure in life," Huard tells Osborne. In fact, his predilections make him perfect for his programming job. To underscore that point, Osborne quotes Huard as saying that he thinks the science departments of universities are filled with Asperger's people. *Wired* magazine reported in 2001 that Asperger's was chic and widespread in Silicon Valley. Osborne wonders if Bill Gates and a host of other driven, technical people don't have it—and if, therefore, we shouldn't celebrate such individuality rather than shun it with pejorative terms like *disease* and *abnormality*.

Certainly, some Asperger's people have a hard time. Osborne profiles Marla, an acerbic recluse who is too paranoid to leave her apartment. But some "normal" people can have similar troubles, Osborne notes. And so he comes to the sweeping conclusion that modern American culture overzealously defines people as abnormal: "American psychiatry embodies a deeply pessimistic, gloomily simplistic view of the world [and is] unable to conceive of a healthy eccentricity or a truly complex individual." Never mind that his cavalier dismissal of psychiatry on the basis of quirky anecdotal evidence betrays a strangely simplistic view of the world as well.

From *American Normal: The Hidden World of Asperger Syndrome*

> "Who among us does not have strange little compulsions and obsessions, which, while not exactly awarding us membership in the Asperger's club, certainly must give us pause about our normality?"



Remarkable Trees of the World

By Thomas Pakenham
W. W. Norton,
$49.95

IN *MEETINGS WITH REMARKABLE TREES*, IRISH TREE SOCIETY CHAIRman Thomas Pakenham shared his photographic portraits of the majestic trees of Ireland and Britain. His lush new coffee-table book chronicles his recent four-year expedition in search of the grandest, oldest, and most visually impressive trees in the world. The trees he photographed include gnarled camphors of Japan, towering sequoias of California, and the alien-looking *Pachypodium geayi,* or "elephant's feet," of Madagascar (above). In the accompanying text, Pakenham provides humorous anecdotes about the natural and cultural histories of the trees, not to mention the sometimes herculean efforts he made to get up close and personal with them. In one such adventure, he risked life and limbs (his own) climbing a 207-foot-tall eucalyptus in Australia. In another, he trekked through terrorist-infested Sri Lanka to photograph the aptly named *Ficus religiosa* tree, thought to be cut from the sprawling fig tree under which Buddha found enlightenment in the sixth century B.C. —*Maia Weinstock*

PHOTOGRAPH COURTESY OF W. W. NORTON.

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In Search of Self

Ancient places in the brain reveal the origins of human identity

By Jennifer Kahn

A FEW MILLION YEARS AGO, A REGION OF THE prefrontal cortex known as Area 10 underwent a mysterious expansion. No one knows what caused this change or why it happened in humans and not other animals. What is known is that people who suffer damage to Area 10 can't remember events from their past. They can still learn and recall facts, but their life experiences vanish. Without such memories, they can't learn from their mistakes. The rest of us know ourselves so well that we can often predict our responses to a situation. People with damage to Area 10 can't access this idea of who they are. They have lost the ability to create a "self."

Liars, Lovers, and Heroes: What the New Brain Science Reveals About How We Become Who We Are

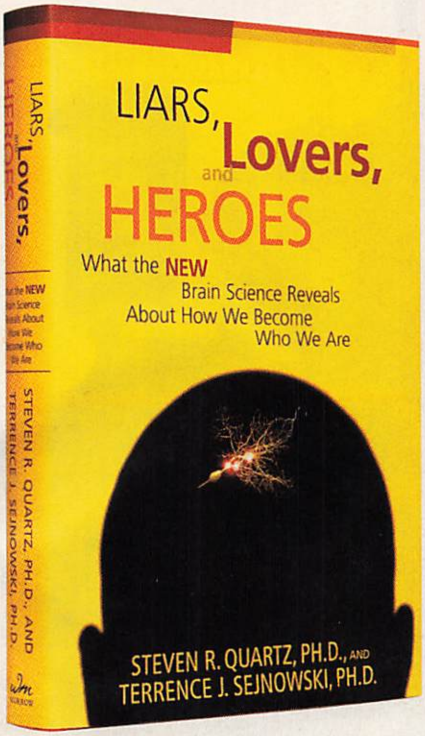
By Steven R. Quartz, Ph.D., and Terrence J. Sejnowski, Ph.D.
William Morrow, $26.95

Searching for oneself used to be a spiritual quest. Now it's a full-on scientific expedition—one documented by neuroscientists Steven Quartz, director of the Social Cognitive Neuroscience Laboratory at Caltech, and Terrence Sejnowski, head of the Computational Neurobiology Lab at the Salk Institute. Expertise is no guarantee of a good book, but *Liars, Lovers, and Heroes* is an entertaining and startling survey of what it means to be human.

Like many good science books, this is at heart a detective story. At issue is not just what distinguishes us from chimpanzees but what makes each of us who we are: that unique admixture of primitive ability melded with regions of higher function. An ancient structure called the ventral tegmental area (VTA) controls our ability to use past experience as a predictor of future reward. Most animals do this to some extent—for instance, by returning to the place where food was abundant the year before. But humans, who combine the VTA and the prefrontal cortex, can see beyond plain causality, tapping into a subtle, continuously updated feedback loop that enables us to defer immediate gratification in favor of rewarding long-term projects, such as learning to play an instrument. Depending on what we find most pleasing, some of us become blues guitarists, others Talmudic scholars.

Fundamentally, though, Quartz and Sejnowski report that "the bridge that carried our ancestors over the mental Rubicon" was the ability to assemble our experiences and qualities into a self we recognize as our own—and to recognize that other people have similar, separate selves. Dating this evolutionary jump is tricky. We know that 40,000 years ago humans began to adorn their dead with precious beads and ivory carvings, the first sign of a belief that our selves were unique, perhaps eternal. But how an idea like this arose is a mystery rooted in still-developing places like Area 10.

Quartz and Sejnowski finally turn from questions of the individual self to problems of society and optimistically recommend neuroscience as the route to community happiness. Once we understand what is required to keep our brains contented, we should be able to construct an environment to satisfy those requirements. The authors hint at a few possibilities: more intimate communities that regularly foster social interactions and cooperative endeavors, lives engineered to encourage a constant flow of new experiences, and opportunities to contribute to the common good. Wishful thinking, perhaps, but then that's one thing that makes our brains uniquely human.


LIARS, Lovers, and HEROES
What the NEW Brain Science Reveals About How We Become Who We Are
STEVEN R. QUARTZ, PH.D., AND TERRENCE J. SEJNOWSKI, PH.D.
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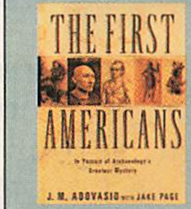
THE FIRST AMERICANS: IN PURSUIT OF ARCHAEOLOGY'S GREATEST MYSTERY

J. M. Adovasio with Jake Page, Random House, $26.95

During a 30-year archaeological excavation in Pennsylvania, Adovasio unearthed a wealth of artifacts, from spear points to fire pits, which indicate humans dwelled in the Americas at least 4,000 years earlier than previously thought. His often startling findings also suggest that the first humans reached the Americas by sea, not land.


THE FIRST AMERICANS
In Pursuit of Archaeology's Greatest Mystery
J. M. ADOVASIO with JAKE PAGE

THE EUREKA! MOMENT: 100 KEY SCIENTIFIC DISCOVERIES OF THE 20TH CENTURY

Rupert Lee, Routledge, $25

The list of "eureka" moments compiled by Lee, a science librarian and former zoologist, includes widely celebrated discoveries—for instance, DNA's double-helix structure and plate tectonics—and lesser-known breakthroughs, such as the classification of blood by type and the realization that nuclear fusion makes stars shine.

THE GOLDEN RATIO: THE STORY OF PHI, THE WORLD'S MOST ASTONISHING NUMBER

Mario Livio, Doubleday Broadway, $24.95

Sunflowers, violins, the Athenian Parthenon, and New York City's Guggenheim Museum share a common attribute. The form of each appears to be governed by a mathematical relationship known as phi, a ratio that equals the nonrepeating number 1.61803 . . . In this exploration of the discovery and appearance of the ratio in mathematics, architecture, art, and science, Livio, an astrophysicist at the Hubble Space Telescope Institute, ponders whether such a seemingly ubiquitous mathematical relationship is intrinsic to the structure of the universe.

THE BACKYARD ASTRONOMER'S GUIDE

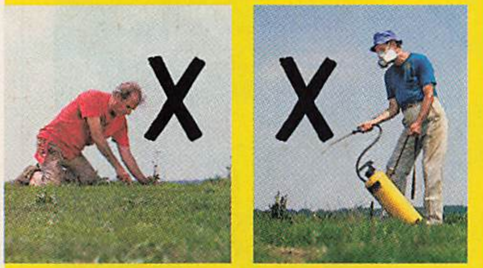
Terence Dickinson and Alan Dyer, Firefly Books, $49.95

This newly expanded, richly illustrated handbook is an ideal stargazing primer. The authors explain how to select and operate the most popular amateur telescopes and how to search for comets, pinwheel galaxies, and supernova remnants. The book also includes a section on how to take your own cosmic photos as well as a portfolio of starscapes, auroras, and eclipses to inspire you.

—Maia Weinstock

PHOTOGRAPH BY JENS MORTENSEN.

Watering chores, water bills! Sweating behind a roaring mower! Spraying poison chemicals and digging weeds...



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bogglers

by scott kim

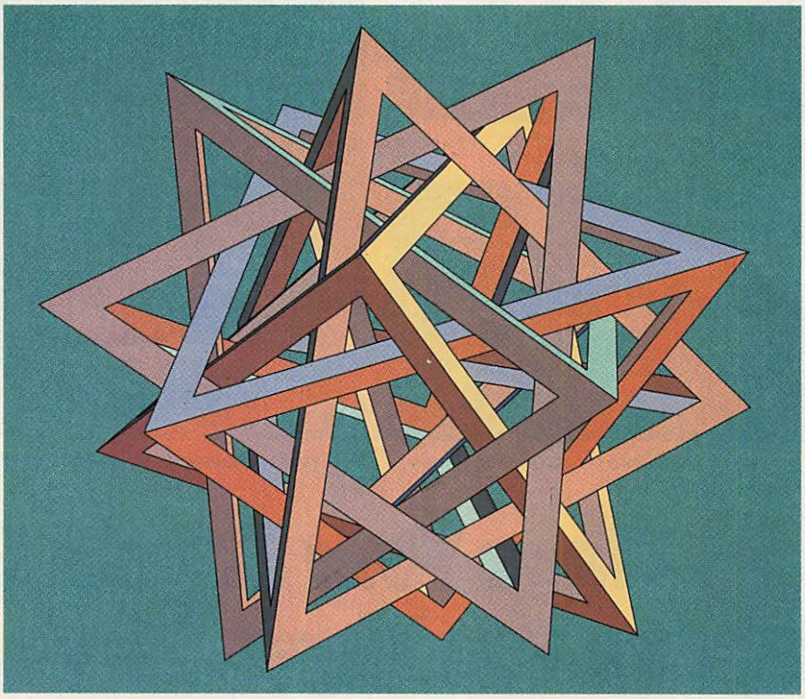
Calculated Risks

Just as the electronic calculator made the slide rule obsolete, sophisticated computer software like Mathematica, Maple, and Derive are trumping calculators. These programs slice through thorny equations with ease, inspiring illustrations, interactive diagrams, and . . . puzzles. The following problems give a taste of what can be dreamed up with this software.

PARENTHETICALLY SPEAKING

Mathematica is complex but still basically a calculator—type in 3 + 5 and it returns 8. But unlike most calculators, Mathematica lets you add parentheses to your expressions. Following the rules of basic algebra, you get different results depending on where you place parentheses. For instance, (3 - 2) - 1 = 0, whereas 3 - (2 - 1) = 2.

1. **[Easy]** List all the different numbers you can make by adding parentheses to the expression 4 - 3 - 2 - 1.
2. **[Difficult]** Find four numbers, *a, b, c,* and *d,* that make *x* equal 1, 2, 3, and 4 when parentheses are used in different ways in the equation $a - b - c - d = x$.
3. **[Difficult]** Which of the numbers 32, 42, 52, 62, and 72 is impossible to make by adding parentheses to the expression 10 + 8 x 6 - 4/2?
4. **[Very difficult]** How many different ways are there to add parentheses to the five-variable expression $a - b - c - d - e$? How many of those ways make different numbers?
5. **[Extremely difficult]** How many different ways are there to add parentheses to the 10-variable expression $a - b/c - d/e - f/g - h/i - j$?



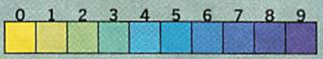
TETRAHEDRAL TANGLE

This convoluted clump was made with Mathematica's tools for drawing three-dimensional shapes. The figure incorporates several tetrahedrons, each with four triangular faces built from six bars that connect four vertices. Study the shape closely, then answer the following questions.

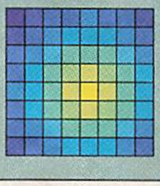
1. **[Easy]** How many tetrahedrons are in this figure?
2. **[Difficult]** If each face of each tetrahedron is counted as a separate triangle, to how many other triangles is each triangle linked? Two triangles are considered linked if they cannot be separated without breaking a bar.
3. **[Difficult]** Examine any two of the tetrahedrons and you will find that they are linked. Can you unlink them by deleting one edge from each of the two tetrahedrons?
4. **[Difficult]** If you draw a line between each corner and its three nearest corners, what type of polyhedron is formed?
5. **[Very difficult]** Imagine each tetrahedron as a solid shape instead of an open framework. What shape is formed by the intersection of all the tetrahedrons? In other words, what shape is the set of points common to all the tetrahedrons?

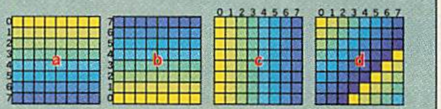
THE PLOT THICKENS

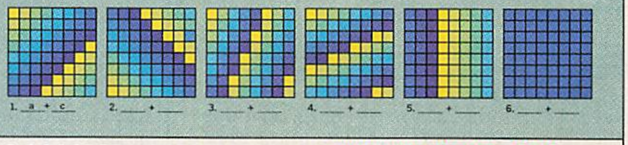
Patterns in numbers are often easier to spot if they're color coordinated. For example, to more clearly understand the pattern represented by the numbers in the grid below, each can be changed to a corresponding color. The colorful new grid reveals a pattern not as easily perceived from numbers alone. Below are four more grids, labeled a, b, c, and d. The numbers along the margins of each grid indicate the number value for each square within a row, column, or diagonal. The numbers within these grids can be added to corresponding numbers in other grids. If you add the value of each square in grid a to the value of the corresponding square in grid c, taking only the last digit of each sum, you get the pattern shown in grid 1. The lower right square in grid a has a value of 7, and the lower right square in grid c also has a value of 7, so the lower right square in grid 1, which represents the sum of a and c, has a value of 4 (the last digit of the sum 7 + 7 = 14). Can you determine which pair of grids a, b, c, or d was added to create each of the grids 2 through 6?



9	8	7	7	6	7	7	8
8	7	6	5	5	5	6	7
7	6	4	3	3	3	4	6
7	5	3	2	1	2	3	5
6	5	3	1	0	1	3	5
7	5	3	2	1	2	3	5
7	6	4	3	3	3	4	6
8	7	6	5	5	5	6	7





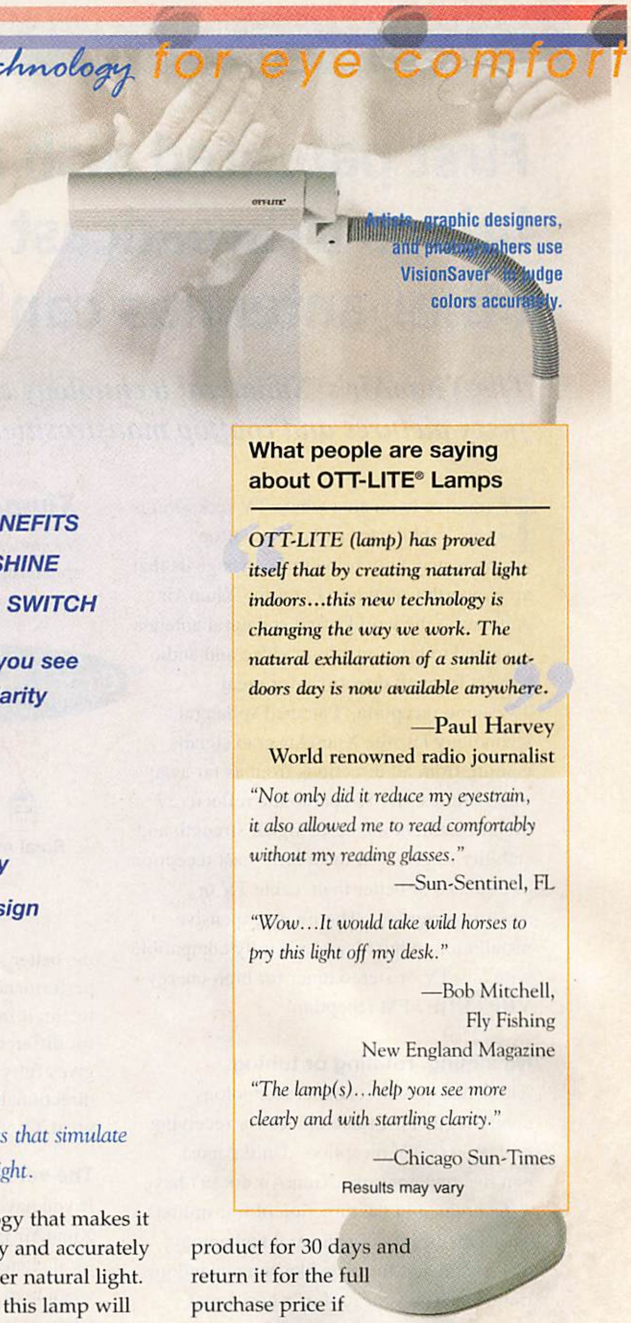


FOR BOGGLERS SOLUTIONS, TURN TO PAGE 87. FOR MORE BOGGLERS PUZZLES, GO TO WWW.DISCOVER.COM.

Lighting Technology for eye comfort

If your eyes have changed… shouldn't your light?

The OTT-LITE® VisionSaver™ Floor Lamp reduces eyestrain caused by glare, and brings the look and feel of natural daylight inside.


OTT-LITE
Artists, graphic designers, and photographers use VisionSaver™ to judge colors accurately.

Designed by a vision expert, this technology helps to enhance the eye's ability to work tirelessly for hours while reading, or at a workstation, by imitating the beneficial wavelengths of natural daylight. OTT-LITE® VisionSaver™ technology, which can reduce eye strain caused by glare, is based on a scientific understanding of the eyes. The results are a new ease in reading, a reduction in eyestrain, and colors and words that jump off the screen. Vision-Saver™ lamps give off extremely low heat and are almost glare-free, resulting in reduceddistortion, increased contrast and visual clarity that is significantly greater than typical cool white lamps. The 10,000-hour bulb uses very low energy while it gives an amazing optical experience.

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- ***See colors true-to-life***
- ***Almost glare-free to reduce eyestrain***
- ***Provides sharp visibility***
- ***Flexible gooseneck design***
- ***10,000 hour bulb***
- ***Low energy usage***
- ***Produces low heat***

OTT-LITE® Natural Light Supplements™—the first lights that simulate the visible wavelengths of sunlight.

What people are saying about OTT-LITE® Lamps

> *OTT-LITE (lamp) has proved itself that by creating natural light indoors…this new technology is changing the way we work. The natural exhilaration of a sunlit outdoors day is now available anywhere.*
>
> —Paul Harvey
> World renowned radio journalist

> *"Not only did it reduce my eyestrain, it also allowed me to read comfortably without my reading glasses."*
>
> —Sun-Sentinel, FL

> *"Wow…It would take wild horses to pry this light off my desk."*
>
> —Bob Mitchell,
> Fly Fishing
> New England Magazine

> *"The lamp(s)…help you see more clearly and with startling clarity."*
>
> —Chicago Sun-Times

Results may vary

The technology that lets you see with startling clarity. Dr. John Nash Ott, a world-renowned scientist, developed the first OTT-LITE® over forty years ago. Dr. Ott spent over forty years researching sunlight and its effect on people, plants and animals. This led to his discovery of OTT-LITE® Natural Light Supplements™—the closest thing to natural daylight. While no light perfectly duplicates sunlight, OTT-LITE® lamps are the next best thing to natural sunlight. The OTT-LITE® lamp has naturally balanced wavelengths in much the same way as sunlight, bringing the benefits of sunlight indoors without heat and glare. Dr. Ott's Natural Light Products utilize a rare earth phosphor blend technology that makes it possible to see almost as clearly and accurately indoors as you do outside under natural light. Practically glare and heat-free, this lamp will change the way you look at your work. These lights also bring the light of a sunny spring day all year long to any room.

See better…with less eyestrain

Dr. John Nash Ott, a scientist with more than forty years experience with lighting technology, developed the first OTT-LITE®. His Natural Light Products utilize a rare earth phosphor blend technology that makes it possible to see almost as clearly and accurately indoors as you do outside under natural light. The result is reduced glare with the OTT-LITE® VisionSaver™ Floor Lamp.

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Try the ultimate lighting technology. The OTT-LITE® VisionSaver™ Floor Lamp provides a difference your eyes can truly feel. The special formulation that brings the feeling of a sunny spring day indoors all year long, is one you'll truly be thankful for. The OTT-LITE® VisionSaver™ Floor Lamp is backed by TechnoScout's exclusive home trial. Try this product for 30 days and return it for the full purchase price if not satisfied, less shipping and handling.

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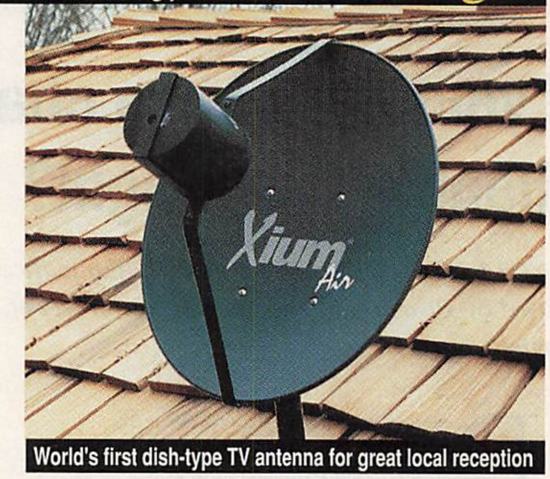
30017

Antenna Technology **Breakthrough**

First patented dish antenna brings in broadcast signals other antennas can't find.

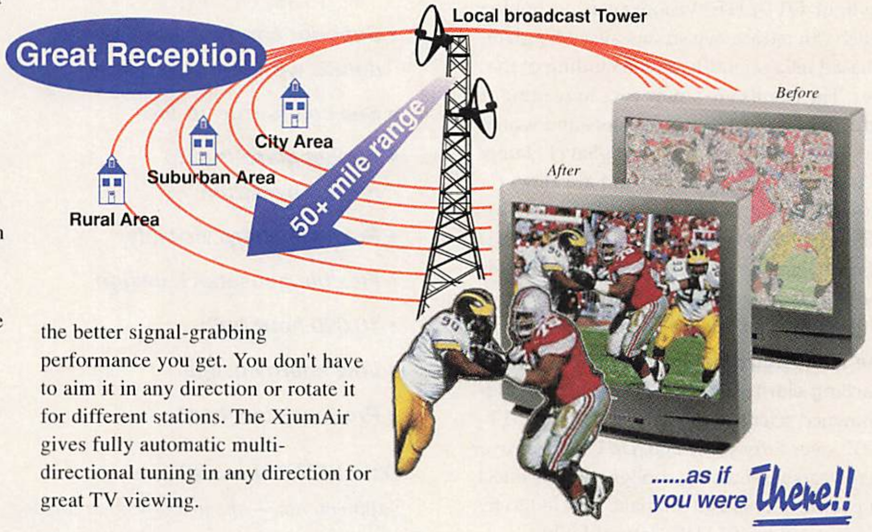
The XiumAir's ™Spilateral technology conquers ghosts, fuzzy pictures and rooftop monstrosities.


World's first dish-type TV antenna for great local reception

If you live in an area where TV reception is weak, 'rabbit ears' and ugly rooftop antennas may only bring in fuzzy signals that aren't worth watching. Enter the XiumAir Antenna -- the world's first spilateral antenna designed to bring in strong video and audio signals from all directions for great TV/stereo reception. Patented spilateral technology lets the XiumAir grab signals coming from all directions from as far away as 50+ miles. Its 18" parabolic reflective / ground element increases signal strength and stability to give you local broadcast reception as good as, or better than, cable TV or satellite reception. There's no expensive installation required, and it's fully compatible with any TV or stereo tuner for high-energy VHF / UHF / FM reception.

XiumAir™ Works!

No matter where you live, the Xium spilateral "dish" antenna will collect all of the signals available, from any direction without the need for rotating or tuning.



No aiming, rotating or tuning.
XiumAir's new 83-channel technology combines an all-in-one device for receiving high-energy TV reception. Unlike most external antennas, the XiumAir doesn't have to be pointed in the direction of transmitters. That's the beauty of spilateral technology. You can mount the dish-like antenna indoors or outside (on your roof or a horizontal mast). The higher the elevation, the better signal-grabbing performance you get. You don't have to aim it in any direction or rotate it for different stations. The XiumAir gives fully automatic multi-directional tuning in any direction for great TV viewing.

The world's first dish-type TV antenna - the last antenna you'll ever need

- NO MORE HUGE, UNSIGHTLY ROOFTOP ANTENNAS
- CLEARER PICTURE AND SOUND
- NO MORE AIMING
- EASY TO INSTALL *Anywhere!!*

The versatile antenna with many uses.
If you have a DSS satellite system, the XiumAir is the ideal complement for receiving local channels without monthly fees. And when high definition broadcast TV arrives in a few years, you will be ready. Plus you can use the antenna now for AM / FM stereo, home-based CB systems, and shortwave radio. The XiumAir Antenna features compact, modern styling that will blend in with almost any decor. The UV-protected housing is made of impact-resistant copolymer, making the exterior resistant to weathering and color change. It includes a standard cable connector for any cable-ready hookup. The XiumAir Antenna delivers maximum local broadcast reception to any television, stereo or any other audio or video receiver, without the use of unsightly, ugly or 'wind damaged' antennas.

Enjoy better TV reception - risk free!
This unique design is the result of years of research and testing, and now you can try it for yourself risk-free. Each XiumAir Antenna System is handcrafted and individually tested for high quality performance. With the XiumAir Antenna, you'll eliminate those unsightly antennas for good. The XiumAir Antenna comes with a 30-day manufacturer's limited warranty and Xium's exclusive risk-free home trial. If you are not satisfied for any reason, just call us for free expert installation assistance, or simply return it within 30 days for a full refund, less S&H.

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resources

The following books, journals, and Web sites provide additional information about topics featured in *Discover* this month.

10 R&D

"Home Remedy for Earth." For more information about the amazing symbiotic relationship between algae and the fungi that we know as lichens, go to www.lichen.com. The site also provides general background on the use of lichens in environmental monitoring and lists some interesting everyday uses of lichens in dyes, foods, and medicines.

"*Galileo* Makes Its Last Stand." For the latest news on the *Galileo* spacecraft, information on the bodies *Galileo* has visited, and a stunning gallery of Jovian images, go to galileo.jpl.nasa.gov.

"Discover Data." Learn more about Conservation International's work, including their current research programs throughout the world, at www.conservation.org.

See the complete world wilderness map at www.nature.com/nsu/021202/movie.html.

Mittermeier, Russell, et al. *Wilderness: Earth's Last Wild Places.* Washington, D.C.: Conservation International, 2003. Hundreds of color photographs and insightful text spotlight Earth's few remaining untamed lands, the lives of those who inhabit them, and the challenges we face preserving these endangered ecosystems.

"Dusting for New Planets." A valuable resource on the study of worlds outside the solar system can be found on the Web site of the Harvard-Smithsonian Center for Astrophysics: cfa-www.harvard.edu/planets. The site includes links to an updated extra-solar planet catalog and overviews on planet detection methods and the search for life outside the solar system.

"Don't Be a Spineless Lover." Truitt, William A., and Lique M. Coolen. "Identification of a Potential Ejaculation Generator in the Spinal Cord." *Science* 297 (August 30, 2002): 1566–1569.

For more, including recent press coverage, see the Lique Coolen lab home page at cellsvr.med.uc.edu/lique.

"Fish Really *Is* Brain Food." Medline, a government-sponsored health Web site, provides a helpful overview of the nature of dementia, its various causes, and related research. See www.nlm.nih.gov/medlineplus/dementia.html.

For information specifically about Alzheimer's disease, see this site created by the National Institute of Neurological Disorders and Stroke: www.ninds.nih.gov/health_and_medical/disorders/alzheimersdisease_doc.htm.

"Landmarks." An account of the life of Marcello Malpighi appears at micro.magnet.fsu.edu/optics/timeline/people/malpighi.html and www.newadvent.org/cathen/09573d.htm.

Learn more about Joseph Priestley at www.woodrow.org/teachers/chemistry/institutes/1992/Priestley.html.

The creation of the Pelican Island bird sanctuary is recounted at midwest.fws.gov/level1/Chronology.pdf, along with other milestones in the 100-year history of U.S. Fish and Wildlife Service conservation efforts.

"Tributes." A brief history of artificial intelligence, courtesy of the American Association for Artificial Intelligence, appears at www.aaai.org/AITopics/bbhist.html. Find out more about the creation of Shakey and its descendant, Flakey, at www.activrobots.com/HISTORY.

A full obituary of Grote Reber appears at education.guardian.co.uk/obituary/story/0,12212,868065,00.html.

"Cracking the Human Behaviorome." Macer, Darryl R. J. "The Next Challenge Is to Map the Human Mind." *Nature* 420 (November 14, 2002): 121.

For an extended version of the proposal for an integrative mental mapping project, see Macer's Web site: www.biol.tsukuba.ac.jp/~macer/mentmap.htm.

Information about the Human Genome Project, including the history and current status of the undertaking, can be found at www.ornl.gov/hgmis.

"The Oils of War." Read "A Regional Strategy to Address Marine Pollution From World War II Wrecks," a draft developed by the South Pacific Regional Environment Programme, based in Apia, Samoa. For this report, as well as the organization's recent projects and newsletters, see the SPREP Web site: www.sprep.org.ws.

"Dangerous Landslides Atop Earth's Core." Muller, Richard A. "Avalanches at the Core-Mantle Boundary." *Geophysical Research Letters* 29 (October 12, 2002): 41-1–41-4.

"Tuning In to Sacred Sounds." "Psychoacoustic Influences of the Echoing Environments of Prehistoric Art." Presented by Steven J. Waller at the Joint Meeting of the 144th Meeting of the Acoustical Society of America, the Third Iberoamerican Congress of Acoustics, and the Ninth Mexican Congress of Acoustics, in Cancún, Mexico, December 4, 2002. A version of the paper is available at www.acoustics.org/press/144th/Waller.htm.

Waller's "Rock Art Acoustics" Web page includes photographs as well as sample audio recordings of an echoing rock-art site: www.geocities.com/CapeCanaveral/9461.

For more about the effort to stop a highway from being built through Petroglyph National Monument in New Mexico, see www.sacredland.org/petroglyph.html.

"What's So Great About Older Men?" For a link to more of Stephen Proulx's research, see Proulx, S. R., T. Day, and L. Rowe. "Older Males Signal More Reliably." *Proceedings: Biological Sciences* (in press), as well as papers on related topics: www.proulxresearch.org/publications.htm.

"Ask the Wizard." For further information describing how X-ray machines work, see www.colorado.edu/physics/2000/xray.

To learn more about the workings and discoveries of NASA's Chandra X-ray Observatory, visit chandra.harvard.edu.

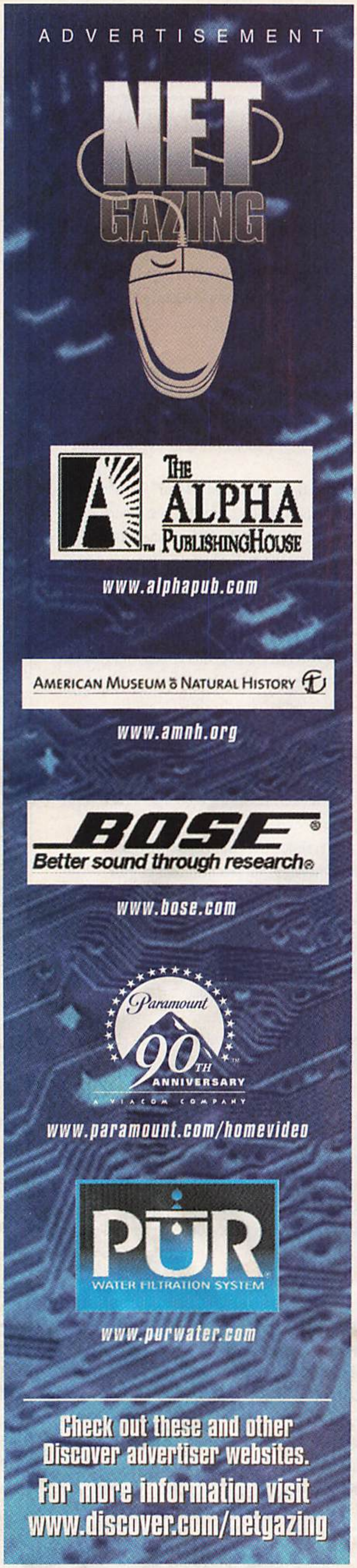
Holtzmann Kevles, Bettyann. *Naked to the Bone: Medical Imaging in the Twentieth Century.* New Brunswick, New Jersey: Rutgers University Press, 1996. Kevles surveys the history of imaging, from Röntgen's first X rays to current technologies that are having deep effects not only on how we view the human body but on our culture and values as well.

"Beyond Breathalyzer." See more details about the device at www.lifepointinc.com.

To learn more about the technology behind the LifePoint device, see the U.S. patents by Frances S. Ligler, et al.: "Flow Immunosensor Method and Apparatus," February 2, 1993, patent number 5,183,740. "Flow Immunosensor Apparatus," June 12, 2001, patent number 6,245,296. Both are available at techtransfer.nrl.navy.mil/intellectual.php or www.uspto.gov/patft/index.html.

Wemhoff, Gregory A., Anne W. Kusterbeck, and Frances S. Ligler. "Drug Detection by Using an Antibody-Based Sensor: The Flow Immunosensor." *NRL Review,* 1991: 103–105.

Kusterbeck, Anne W., Gregory A. Wemhoff, and Frances S. Ligler. "Antibody-Based Biosensor for Continuous Monitoring," in *Biosensor Techology:*



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Fundamentals and Applications, edited by Richard P. Buck, William E. Hatfield, Mirtha Umaña, and Edmond F. Bowden. New York: Marcel Dekker Inc., 1990.

Frances S. Ligler's Web page has more on optical biosensors: cbmsews1.nrl.navy.mil/fsl.

"Discover Dialogue." The recent study of Walter Willett's Healthy Eating Pyramid appeared in McCullough, Marjorie L., et al. "Diet Quality and Major Chronic Disease Risk in Men and Women: Moving Toward Improved Dietary Guidance." *The American Journal of Clinical Nutrition* 76 (December 1, 2002): 1261–1271. View an abstract at www.ajcn.org.

A complete description of the science underlying the Healthy Eating Pyramid appears in Walter Willett's book *Eat, Drink, and Be Healthy: The Harvard Medical School Guide to Healthy Eating* (New York: Simon & Schuster, 2001).

Willett's home page describes his current research and offers links to relevant articles and Web sites: www.hsph.harvard.edu/faculty/WalterWillett.html.

"Surgery by Sunlight." Gordon, Jeffrey, D. Feuermann, and M. Huleihil. "Laser Surgical Effects With Concentrated Solar Radiation." *Applied Physics Letters* 81 (September 30, 2002): 2653–2655.

19 EMERGING TECHNOLOGY

Find a brief description of the workings of swarm music, links to papers, and a list of upcoming live swarm-music performances at Tim Blackwell's site: www.timblackwell.com. The site also has playable audio samples taken from the two swarm-music CDs, *Swarm Music* and *Autumn Missed,* which are available for purchase.

Recent books by Steven Johnson:
Emergence: The Connected Lives of Ants, Brains, Cities, and Software. New York: Scribner, 2001.
Interface Culture: How New Technology Transforms the Way We Create and Communicate. New York: Basic Books, 1999 (reprint edition).

22 VITAL SIGNS

The Centers for Disease Control has posted extensive rabies information online. See www.cdc.gov/ncidod/dvrd/rabies.

Read a brief biography of Louis Pasteur at ambafrance-ca.org/HYPERLAB/PEOPLE/_pasteur.html.

24 WORKS IN PROGRESS

Schopf, J. William. *Cradle of Life: The Discovery of Earth's Earliest Fossils.* Princeton: Princeton University Press, 1999.

26 THE PHYSICS OF... NEGATIVE PRESSURE

The Massachusetts Maple Producers Association explains sap flow and touches on the mysteries of negative pressure: www.massmaple.org/flow.html.

Read the Works in Progress article that started the whole brouhaha: "Antigravity Plumbing," *Discover,* September 2002, available at www.discover.com.

28 SKY LIGHTS

The Views of the Solar System site has an informative overview of the asteroids, with a section devoted specifically to Vesta. See www.solarviews.com/eng/asteroid.htm.

Science historian Michael Hoskin has written a detailed analysis of the events leading up to the discovery of the first asteroids. See www.astropa.unipa.it/versione_inglese/Hystory/BODE'S_LAW.htm.

Asteroids: A History by Curtis Peebles (Washington, D.C.: Smithsonian Institution Press, 2000) covers the history of asteroids, from the discovery of the first ones to the latest scientific theories about them.

Meteorites and Their Parent Planets (second edition) by Harry McSween (New York: Cambridge University Press, 1999) gives a somewhat technical but very readable account of how scientists study meteorites and trace them back to asteroids such as Vesta.

32 THE BRAIN AND EMOTIONS: FEAR

For more from Joseph LeDoux, see *The Emotional Brain: The Mysterious Underpinnings of Emotional Life* (New York: Touchstone Books, 1996), or visit the LeDoux laboratory home page at www.cns.nyu.edu/home/ledoux.

For a look at current research on fear, see the Web page of the New York University Center for the Neuroscience of Fear and Anxiety at www.cns.nyu.edu/CNFA.

For a historical view of the science behind emotions, check out the Salk Institute's Emotion home page at emotion.salk.edu/emotion.html.

For an interview with LeDoux, see "Parallel Memories: Putting Emotions Back Into the Brain: A Talk With Joseph LeDoux" at www.edge.org/3rd_culture/ledoux/ledoux_p2.html. For an audio interview, check out National Public Radio's March 29, 2002, *Science Friday* segment, "Synaptic Self" at www.sciencefriday.com/pages/2002/Mar/hour2_032902.html.

Learn more about fear, specifically the role of the amygdala in post-traumatic stress disorder: "Kernel of Fear" by Mark Caldwell, *Discover,* June 1995. This article is available at www.discover.com.

40 THE HARDY SARAH BLAFFER HRDY

Selected books by Sarah Blaffer Hrdy:

Mother Nature: Maternal Instincts and How They Shape the Human Species. New York: Ballantine Books, 2000.

The Woman That Never Evolved. Cambridge: Harvard University Press, 1999.

The Langurs of Abu: Female and Male Strategies of Reproduction. Cambridge: Harvard University Press, 1997.

Read about Sarah Blaffer Hrdy's research on primate infanticide in "First, Kill the Babies" by Carl Zimmer, *Discover,* September 1996. This article is available at www.discover.com.

Jolly, Alison. *Lucy's Legacy: Sex and Intelligence in Human Evolution.* Cambridge: Harvard University Press, 1999.

Trivers, Robert. *Natural Selection and Social Theory: Selected Papers of Robert Trivers.* New York: Oxford University Press, 2002.

Altmann, Jeanne. *Baboon Mothers and Infants.* Chicago: University of Chicago Press, 1980; reissued 2001.

Solomon, Nancy G., and Jeffrey A. French, editors. *Cooperative Breeding in Mammals.* New York: Cambridge University Press, 1997.

Cassidy, Jude, and Phillip R. Shaver, editors. *Handbook of Attachment.* New York: Guilford Press, 1999.

A PDF of Hrdy's 2001 Tanner Lectures, "Mothers and Others," can be viewed at www.tannerlectures.utah.edu/lectures/Hrdy_02.pdf. An abridged version of the lecture appeared in *Natural History,* May 2001, and is available online at www.amnh.org/naturalhistory/0501/0501_feature.html. This article also appears in *The Best American Science Writing 2002,* edited by Matt Ridley (Ecco Press, 2002), and in *The Best American Science and Nature Writing 2002,* edited by Natalie Angier and Tim Folger (Houghton Mifflin, 2002).

46 AIBO

The Sony Computer Science Laboratories Paris Web site describes their AIBO research and features a video clip of the Belgian shepherd attacking AIBO: www.csl.sony.fr/Research/Experiments/DogAIBO/index.php.

At www.aibo.com, Sony's slick AIBO consumer site, view the full AIBO lineup along with the accessories and software that can be purchased to enhance the robodogs.

A paper by Barbara Webb explores the usefulness of robots in animal behavior studies. "Can Robots Make Good Models of Biological Behavior?" *Behavioral and Brain Sciences* 24 (6) 2001. An abstract is available at www.bbsonline.org.

Learn about Barbara Webb's current research at Stirling University in England, including work using robots to model crickets: ganglion.stir.ac.uk.

NOVA Online interviewed Gerald Borgia about his bowerbird research, including the robotic bowerbird created by Gail Patricelli: www.pbs.org/wgbh/nova/bowerbirds/trail.html.

Patricelli, Gail L., J. Albert C. Uy, Gregory Walsh, and Gerald Borgia. "Sexual Selection: Male Displays Adjusted to Female's Response." *Nature* 415 (January 17, 2002): 279–280.

There are more photographs and information about the ratbot on Atsuo Takanishi's Web site. In addition to the ratbot, the lab has worked on a flutist robot and a dental robot. Check them all out at www.takanishi.mech.waseda.ac.jp.

54 SURVIVOR

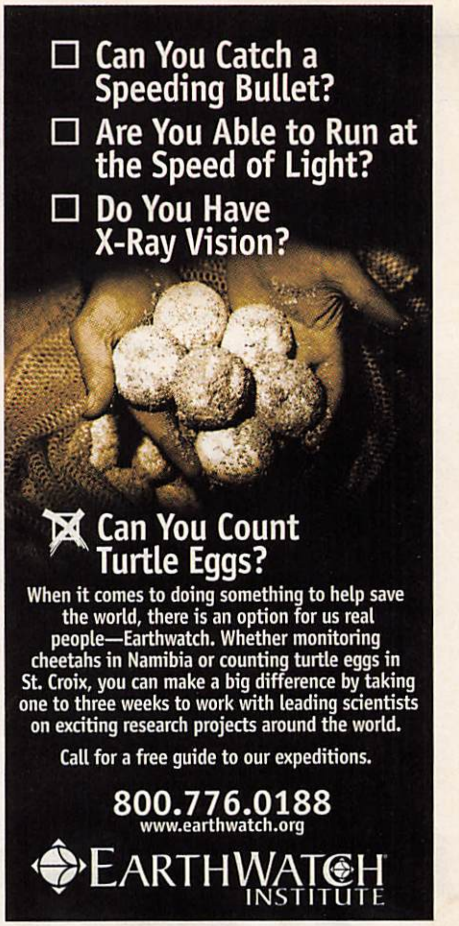
For more on the Dmanisi site, with history, photographs, research updates, and links to recent articles, see the excellent Georgian Center of Prehistoric Research page at www.dmanisi.org.ge/index.html.

Learn more about the debate on human origins from the Smithsonian Institution's Human Origins Program at www.mnh.si.edu/anthro/humanorigins.

For an interactive tour through our evolutionary heritage, complete with lovely visuals and lucid explanations, see the University of Arizona's Becoming Human site at www.becominghuman.org.

For an overview of what the Dmanisi skull means, see Balter, Michael, and Ann Gibbons, "Were 'Little People' the First to Venture Out of Africa?" *Science* 297 (July 5, 2002): 26–27.

For an excellent review of the evolution of modern humans, featuring interactive time lines, links to current news, a comprehensive Web guide, and opinion pieces by top researchers, see the BBC's Adventures in Human Evolution site: www.bbc.co.uk/science/apeman.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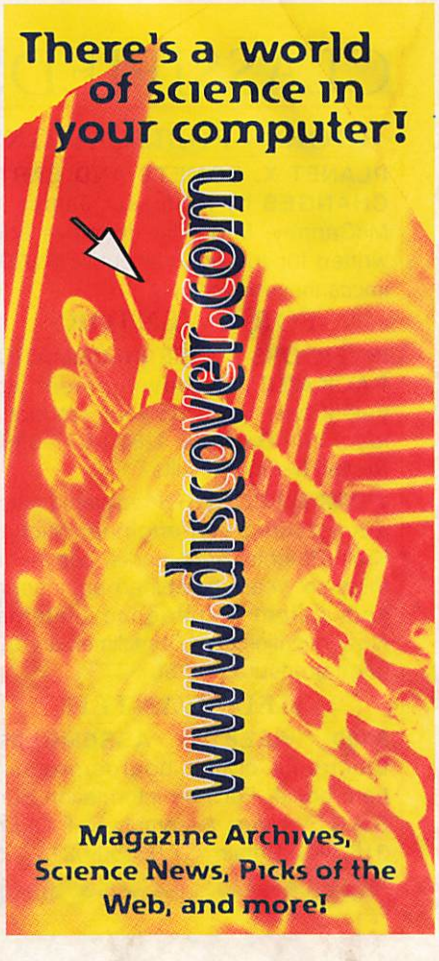
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Read an overview of the Toumaï skull's significance: Wood, Bernard. "Paleoanthropology: Hominid Revelations From Chad." *Nature* 418 (July 11, 2002): 133–135.

For our family tree, as well as a complete and lucid compilation of early hominid findings and what they mean, see NOVA's human origins site at www.pbs.org/wgbh/evolution/humans/humankind/k.html.

60 ARE WE READY FOR ALIEN ORGANISMS?

The National Research Council released a report in 2002 detailing the problems and challenges involved in Martian sample return. "The Quarantine and Certification of Martian Samples" is available online at www.nap.edu/books/0309075718/html/index.html.

NASA's Jet Propulsion Laboratory has an online catalog of all past, present, and future missions to Mars: mars.jpl.nasa.gov/missions/index.html.

Check out the Web site of the Southwest Foundation for Biomedical Research to learn about some of the other research being conducted at the biosafety level-four facilities: www.sfbr.org.

66 OH, DEER

Cultural anthropologist Richard Nelson documents America's current love-hate relationship with deer in *Heart and Blood: Living With Deer in America*. New York: Vintage Departures, 1997.

Wisconsin's Department of National Resources Web site has information about living with deer, as well as wildlife management and wildlife diseases: www.dnr.state.wi.us.

The Chronic Wasting Disease Alliance Web site features news, policy information, and recommendations for hunters regarding CWD: www.cwd-info.org.

72 REVIEWS

The Royal Academy of Arts offers a virtual tour of the Aztec exhibit, including spectacular photographs of some of the works on view: www.aztecs.org.uk.

Learn about Aztec history and Mesoamerican archaeology at www.ancientmexico.com and emuseum.mnsu.edu/archaeology/sites/meso.html.

For more about astrophysicist Robert Kirshner, author of *The Extravagant Universe*, go to his home page at cfa-www.harvard.edu/hco/astro/people/homepages/kirshner.html.

There's a wealth of Asperger's resources on the Web, as well as a number of family support networks. Just a few of them are: users.wpi.edu/~trek/aspergers.html; www.udel.edu/bkirby/asperger; and www.aspergers.com.

80 BOGGLERS

For more on Mathematica, go to www.wolfram.com; for Maple, see www.mapleapps.com, and for Derive, go to www.chartwellyorke.com.

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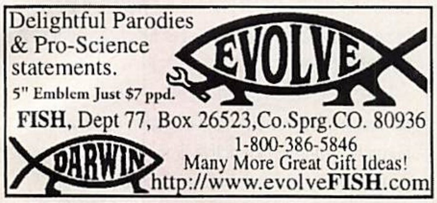

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There are more puzzles and inventions by Scott Kim on his Web site, www.scottkim.com, where you will also find an archive of his monthly Bogglers columns, a Bogglers discussion board, and other amusements for your mind.

Also check out Scott's creative "inversions"—upside-down lettering—on his Web site and in his book *Inversions: A Catalog of Calligraphic Cartwheels* (Emeryville, Calif.: Key Curriculum Press, 1996). To order, go to www.keypress.com.

BOGGLERS SOLUTIONS

PARENTHETICALLY SPEAKING

1. –2, 0, 2, and 4

2. $a = 4.5$, $b = 2$, $c = 1$, $d = .5$ is one solution. The first number minus the second must be 2.5, and the second two numbers must be 1 or –1 and .5 or –.5, in either order.

3. You cannot make 62 by adding parentheses to the expression $10 + 8 \times 6 - 4/2$. Here are the ways to make the other numbers:

$32 = 10 + (((8 \times 6) - 4)/2)$

$42 = 10 + (8 \times (6 - (4/2)))$

$52 = (((10 + 8) \times 6) - 4)/2$

$72 = (10 + 8) \times (6 - (4/2))$

4. There are 14 ways to add parentheses to the five-variable expression $a - b - c - d - e$, of which eight make different numbers. Adding parentheses to $a - b - c - d - e$ has the effect of essentially allowing us to choose whether the last three variables c, d, and e are added to or subtracted from the quantity $(a - b)$. Multiplying together the two choices (parentheses or no parentheses) for the three variables gives us $2 \times 2 \times 2 = 8$, or eight choices altogether. Normally, each of these eight choices makes a different number, unless we choose exceptional values like $c = d = e = 0$.

Here are the 14 ways to add parentheses to the expression $a - b - c - d - e$. The list is divided into four parts: adding parentheses to *a* and *bcde*, *ab* and *cde*, *abc* and *de*, and *abcd* and *e*.

$a - (b - (c - (d - e)))$

$a - (b - ((c - d) - e))$

$a - ((b - c) - (d - e))$

$a - ((b - (c - d)) - e)$

$a - (((b - c) - d) - e)$

$(a - b) - (c - (d - e))$

$(a - b) - ((c - d) - e)$

$(a - (b - c)) - (d - e)$

$((a - b) - c) - (d - e)$

$(a - (b - (c - d))) - e$

$(a - ((b - c) - d)) - e$

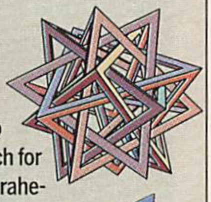
$((a - b) - (c - d)) - e$

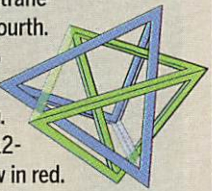
$((a - (b - c)) - d) - e$

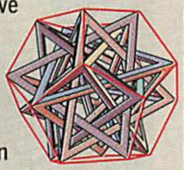
$(((a - b) - c) - d) - e$

5. There are 4,862 ways to add parentheses to the 10-variable expression $a-b/c-d/e-f/g-h/i-j$. The numbers that count the ways to parenthesize an n-variable expression are called the Catalan numbers, after 19th-century mathematician Eugène Charles Catalan. The first few Catalan numbers are 1, 1, 2, 5, 14, 42, 132, 429, 1,430, and 4,862. Like the Fibonacci numbers, each Catalan number can be computed from the previous Catalan numbers. They also specify, among other things, the number of ways to dissect a polygon with $n + 2$ sides into triangles.

TETRAHEDRAL TANGLE







1. The shape is made of five tetrahedrons.

2. Each triangle is linked to six other triangles: two each for three of the four other tetrahedrons, and none for the fourth.

3. Here is how to unlink two tetrahedrons by deleting just one edge from each.

4. A dodecahedron, a 12-sided figure, shown below in red.

5. The intersection of all five tetrahedrons is an icosahedron, a regular shape of 20 triangular faces. The key is to realize that each triangular face of a tetrahedron lies in a plane perpendicular to a line from the center of the figure to the fourth corner of the tetrahedron. This means that the 20 planes containing the 20 faces of the tetrahedrons are arrayed in the same symmetry as the corners of the dodecahedron above. The regular dodecahedron and icosahedron have what is known as a "dual" relationship: The corners of one shape can be constructed as the centers of the faces of the other shape, and both have the same symmetries. In other words, there are as many faces in the icosahedron as there are vertices of the dodecahedron.

THE PLOT THICKENS

1. a + c

2. b + c

3. c + d

4. a + d

5. b + d

6. a + b

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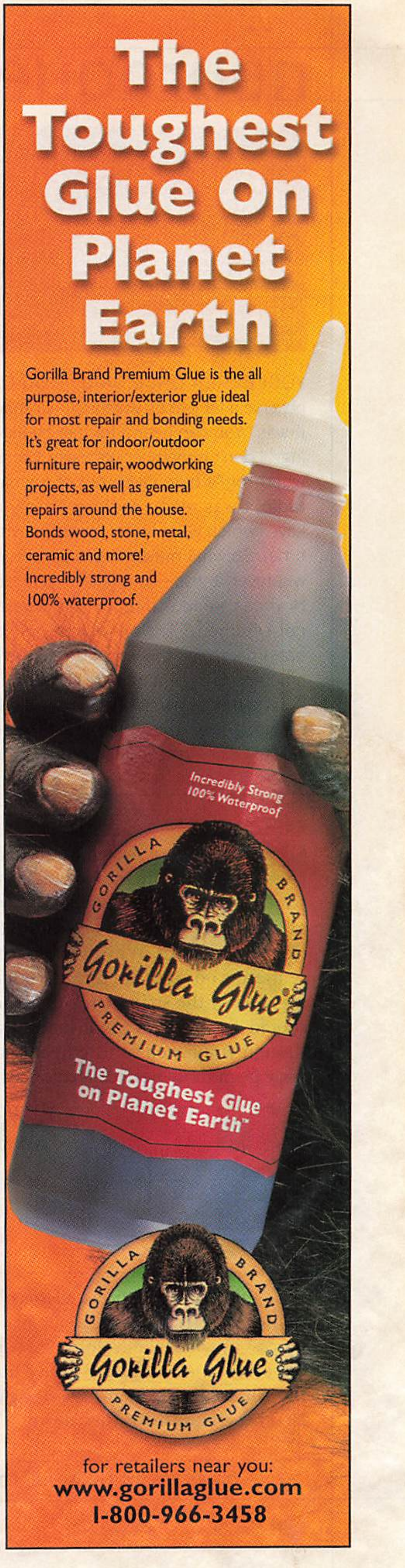

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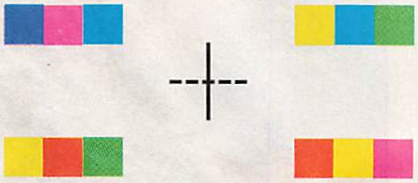
Your Selective Field of View

How your brain can focus on what it wants to see

YOGI BERRA ONCE SAID, "YOU CAN observe a lot just by watching." Or maybe it was "You can hear a lot just by listening." I don't remember precisely, because when Yogi's quip came out of my clock radio, I was madly looking for my car keys (which were in my hand the whole time). So what makes Yogi's aphorism—whatever it was—so maddeningly true? How can we look directly at things and not see them? The answer is that your brain perceives the world through what amounts to a mental "soda straw." When it aims that straw at one thing, all other objects—even those within your direct field of vision—recede into the background.

EXPERIMENT 1

Keeping your gaze riveted on the black cross, below, at all times, and holding the page 10 inches or less from your eyes, say the names of the three colors in each of the four strips. While you are concentrating on—but not directly looking at—one of the strips, the other three should dim in your consciousness, even though you haven't shifted your gaze away from those neglected color strips.



Cognitive psychologists call this phenomenon selective attention, a neural process by which the "volume knob" on one set of sensory inputs is turned up at the same time the intensity settings of all other stimuli are turned down.

EXPERIMENT 2

Having fiddled with the mental "controls" that steer your awareness toward different locations, now learn how it's possible to filter incoming information according to other attributes, such as color. Focus on the cross again, but this time say aloud the name of each of the six distinct colors, immediately followed by the total number of times that particular color appears on all four strips. Notice that in contrast with experiment 1, in which you couldn't concentrate on more than one strip at a time, here your soda straw widened its "field of view" to take in all four strips at once as it registered multiple instances of single colors. In addition to its other controls, your mental soda straw appears to have a zoom knob.

EXPERIMENT 3

Your brain calls up remembered images through the same conduit it uses to take them in live. Close your eyes and visualize everything inside your living room, including the furniture, walls, and artwork. As you scan your memory, notice that even though your brain stores the contents of your living room in surprising detail, it only "sees" these objects one at a time, more or less. You may be able to "zoom out" to recall several parts of your living room at once, but when you do, the details of individual objects will become a mental blur. This blurring effect illustrates an important property of selective attention: Your brain not only discards information that's outside the soda straw but is able to slurp up only a limited amount of detail *within* the soda straw as well.

To make matters worse, inputs from all your sense organs must flow through the same narrow straw and may block each other. For instance, talking on a cell phone while driving "blinds" you to important details about traffic. This may explain why dipping your mental soda straw into an active phone conversation while driving is equivalent to dipping it into a stiff shot of whiskey. ☒

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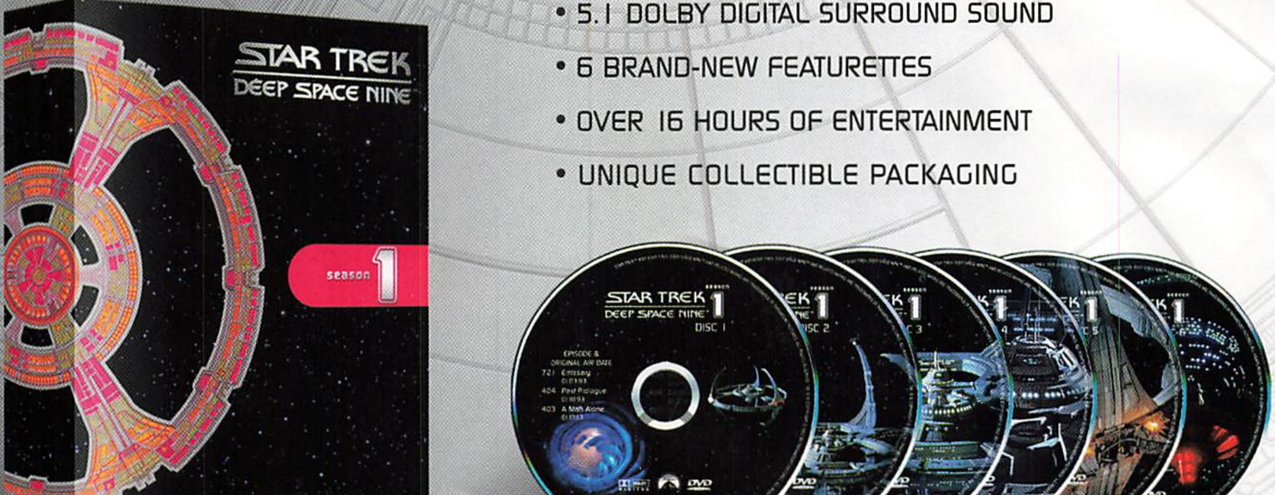

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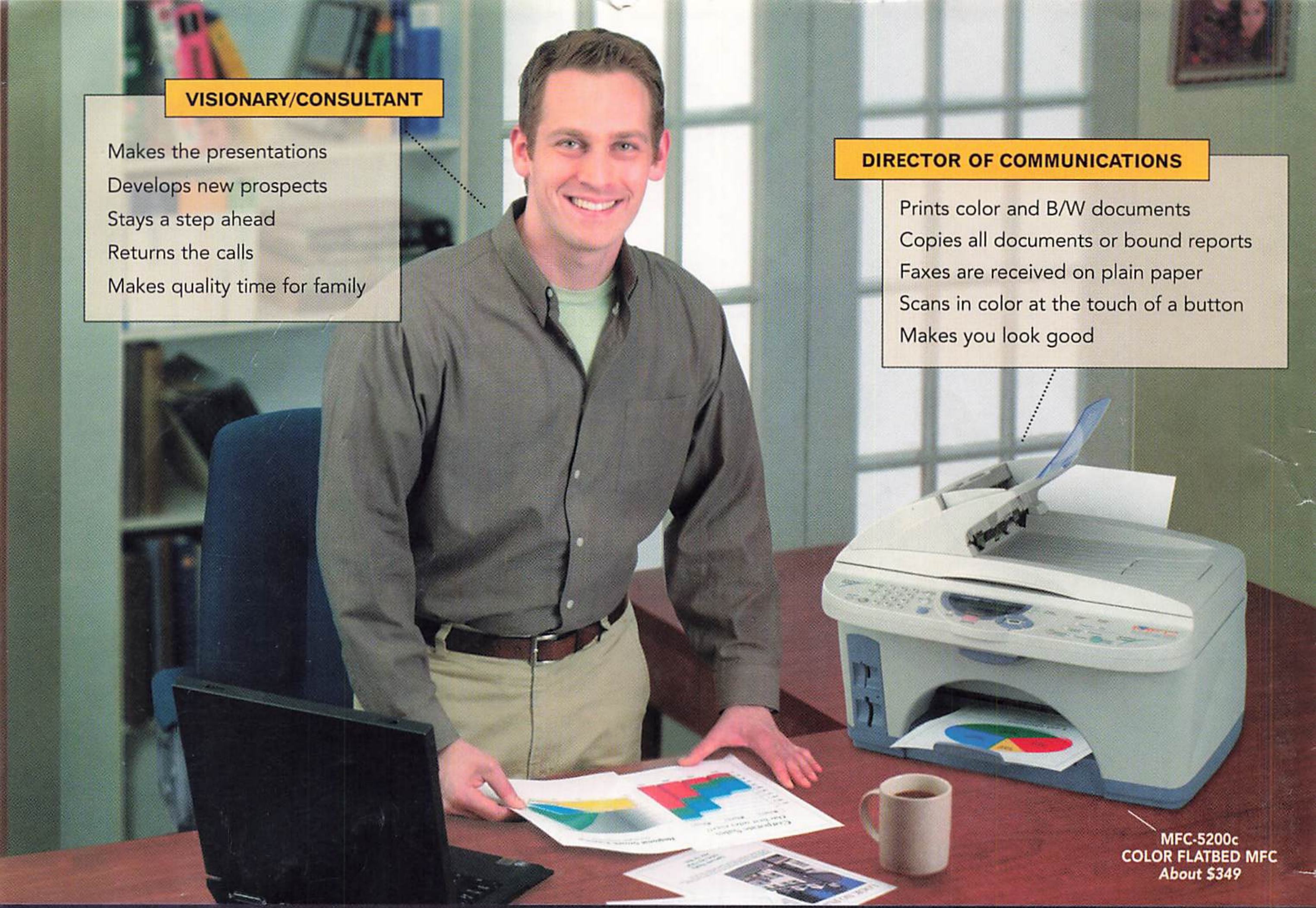

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